AD

AD-E400 171

TECHNICAL REPORT ARLCD-TR-77010

A TECHNIQUE FOR ASSESSING THE DURABILITY OF STRUCTURAL ADHESIVES

RAYMOND F. WEGMAN
MARIE C. ROSS
ELIZABETH A. GARNIS
STANLEY A. SLOTA

MAY 1978

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Technical Report ARLCD-TR-77010	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

A TECHNIQUE FOR ASSESSING THE DURABILITY OF STRUCTURAL ADHESIVES

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

Raymond F. Wegman
Elizabeth A. Garnis
Marie C. Ross
Stanley A. Slota

8. CONTRACT OR GRANT NUMBER(s)

AMCMS 502E.11.295.4010
7380.17.A50Q.3

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Material Engineering Division, FRL
Picatinny Arsenal
Dover, NJ 07801

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

ARRADCOM
ATTN: DRDAR-TSS
Dover, NJ 07801

12. REPORT DATE

May 1978

13. NUMBER OF PAGES

49

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

ARRADCOM, LCWSL
ATTN: DRDAR-LCA
Dover, NJ 07801

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Adhesives	Hot-water-soak	FPL etch
Bonding	Residual-strength	Anodize
Durability	Aluminum	Phosphate fluoride etch
Lap shear	Titanium	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A new method for inexpensively evaluating the durability of a large number of adhesives was developed and evaluated. This test method enables an investigator to simultaneously evaluate many adhesive-adherend variations and to estimate the durability of the variations under conditions of load, temperature, and humidity. The method will save time and money in the screening process used

20. ABSTRACT (Continued)

to select the best adhesives and adherend surface treatments for a particular application. The method involves determining the residual strength after the bonded joints are immersed in 60°C water for prescribed periods of time.

Data are presented for twelve structural adhesives which are 121°C (250°F) curing systems. The adherends used were 2024T3 aluminum, either acid-dichromate (FPL) etched or anodized, 6 A1-4V titanium and commercially pure (CP) titanium, both phosphate-fluoride etched.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of Dr. David W. Levi for his invaluable assistance in preparing this report for publication.

TABLE OF CONTENTS

INTRODUCTION

The durability of adhesive-bonded joints has been evaluated a number of times (refs. 1-30). One method used (ref. 26) involves applying stress to the joint and subsequently exposing the stressed joint to a test environment. This is expensive and time consuming because it requires environmental test chambers.

A new test has been developed (ref. 31) in which a large number of specimens can be conditioned unstressed, simultaneously, and tested for residual strength. The results can be compared to rank the adhesive joints in order of durability. By combining this new test with the data for a single stress level test, a prediction curve for the behavior of the joints under the ASTM D-2919-71 test can be prepared (ref. 31-34).

DISCUSSION

The twelve adhesive systems used in this investigation are listed in table 1. All are 121°C (250°F) curing systems. The adherends and their surface preparations are as follows:

1. 2024-T3 aluminum alloy, acid-dichromate (FPL) etched or anodized.

2. Commercially pure (CP) titanium alloy, phosphate-fluoride etched.

3. 6 A1-4V titanium alloy, phosphate-fluoride etched.

References 32 and 33 show that the hot-water soak test gives a pattern of results similar to those obtained from the stressed durability tests for 121°C (250°F) adhesives. Plotting the time-to-failure data obtained at one stress level at 60°C and 95% relative humidity (RH) and the hot-water soak/residual strength data on the same graph, and drawing a line parallel to the hot-water soak line, yields a prediction curve for the stressed durability test (fig. 21). The prediction curve origin is taken at the average of the time-to-failure at the stress level chosen.

Figures 1 through 23 summarize graphically all the data obtained in this program. Most of the graphs contain hot-water soak and stressed durability curves along with a prediction curve. Figures 21 through 23 contain only the hot-water soak curve and a prediction curve based on one set of time-to-failure data. The slope of the actual curve may vary from the slope of the predicted curve; most of the differences are considered within experimental error due to the scatter expected in adhesive mechanical data. Reference 35 shows that a reasonable estimate of lifetime can be obtained from hot-water aging data for some of the adhesive systems which were studied in this investigation.

Some comments on the individual plots are given in table 2.

For each set of data, the stressed-durability test is generally quicker than the hot-water soak test. If a large number of adhesive-adherend combinations are to be tested, however, the hot-water soak test will be faster and will cost less. Water-soak specimens can be conditioned without using stress fixtures, large environmental chambers, or extensive instrumentation. Only the temperature-controlled water bath and standard tensile testing equipment are required.

In reference 34, the hot-water soak/residual-strength test was used to monitor the storage lives of D, I, K, and L adhesives. The adhesives were stored at -20°C (-4°F) immediately after their manufacture and removed monthly for specimen preparation. Figure 24 is the graphic presentation of the results for the systems. The 1000 hour hot-water soak/residual-strength curve shows a substantial decrease for adhesive sample I at 9 months, indicating that the maximum useful storage life of the adhesive at -20°C is 8 months. For adhesives K and L, the storage life at -20°C was at least 13 months. Adhesive D slowly decreased in durability after 7 months storage.

EXPERIMENTAL PROCEDURES

Preparation of Adherends

The 2024-T3 aluminum alloy was etched with acid-dichromate (FPL) etch as described in reference 32. The anodized 2024-T3 aluminum was prepared as described in reference 32. The CP and 6 A1-4V titanium were prepared as described in reference 21.

Methods of Testing

Lap-Shear Tensile Strength

A Baldwin Universal Test Machine was used for load application. The load rate was 16.5 MPa (2400 psi)/minute.

Hot-Water Soak/Residual-Strength

Adhesive-bonded, lap-shear specimens were immersed for a prescribed time in a thermostatically controlled tank at 60°C (140°F). The specimens were removed and placed in a 60°C (140°F) container of water. The water container, with the specimens inside, was placed in the test chamber of a Baldwin Tensile Test Machine at 60°C (140°F). The individual specimen to be tested was removed from the water container and placed in the test grips. A thermocouple was attached with adhesive tape. When the digital thermometer attached to the thermocouple registered 60°C, the specimen was tested to failure to determine its residual strength after the hot-water immersion.

Stressed Durability

The stressed-durability testing was done in accordance with the basic method described in reference 26 except that the fixtures were equipped with a timing device to record the elapsed time the specimens were under test before failure. This timing device is descrived in reference 18.

Mathematical Calculation of the Best Fit of Data for Durability Curves

The data was processed with a Hewlett Packard 9100A calculator using the Hewlett Packard program 09101-70803. This program calculates the equation of the straight line of best fit of a set of data points. The best fit is determined by minimizing the sum of the squares of the deviations of the data points from the line.

The program claculates m and b for the equation

$$Y = mX + b. \tag{1}$$

The program also calculates a correlation coefficient r, an indication of goodness of fit. Note $-1 \leq r \leq 1$ where the sign corresponds to the slope m. If $r = 0$ there is no correlation, and if $r = \pm 1$ there is perfect correlation or a perfect fit.

The defining equations taken from reference 36 are

$$m = \frac{\sum_{i=1}^{n} (X_i - \bar{X})\ (Y_i - \bar{Y})}{\sum_{i=1}^{n} (X_i - \bar{X})^2} \tag{2}$$

$$b = \bar{Y} - m\bar{X} \tag{3}$$

where

$$\bar{Y} = \frac{\sum_{i=1}^{n} Y_i}{n} \tag{4}$$

and

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{5}$$

$$r = \frac{\sum_{i=1}^{n} (X_i - \bar{X})\ (Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2\ \Sigma\ (Y_i - \bar{Y})^2}} \tag{6}$$

The program was adapted to change the x axis data to log x for convenient use with semilog graph paper.

Conversion to SI Units

Conventional stress units of pounds per square inch (psi) were converted to SI units by the following:

$$\frac{\text{psi} \times 6.8948}{1000} = \text{MPa}$$

This was in accordance with ASTM E 380-74, table 4.

CONCLUSION AND RECOMMENDATION

The hot-water soak/residual-strength test described in this report can inexpensively predict the stressed durability of many 121°C curing/adhesive-adherend combinations. This method needs only one set of stressed data for each combination.

Further evaluation should be made for other adhesive systems, especially those cured at temperatures above 121°C.

REFERENCES

1. E. D. Newel and G. Carrillo, "A New Surface Preparation Process for Titanium," Materials and Processes for the 70's--Cost Effectiveness and Reliability, National SAMPE Technical Conference Series 1973, pp 131-144.

2. G. W. Lively and A. E. Hohman, "Development of a Mechanical-Chemical Surface Treatment for Titanium Alloys for Adhesive Bonding," Materials and Processes for the 70's--Cost Effectiveness and Reliability, National SAMPE Technical Conference Series 1973, pp 145-159.

3. N. L. Rogers, "A Comparative Test for Bond Line Corrosion: Clad vs Bare Aluminum Alloys," Materials and Processes for the 70's--Cost Effectiveness and Reliability, National SAMPE Technical Conference Series 1973, pp 160-183.

4. J. F. Coleman, "Durability Studies on Toughened Acrylic Resin Adhesives," Materials and Processes for the 70's--Cost Effectiveness and Reliability, National SAMPE Technical Conference Series 1973, pp 518-523.

5. R. B. Krieger, Jr, "Evaluating Structural Adhesives Under Sustained Load in Hostile Environment," Materials and Processes for the 70's--Cost Effectiveness and Reliability, National SAMPE Technical Conference Series 1973, pp 643-668.

6. F. D. Swanson and S. J. Price, "The Chemistry of Urethane Adhesives Incorporating Silane Coupling Agents," Non-Metallic Materials Selection, Application, and Environmental Effects, National SAMPE Technical Conference Series 1972, pp 399-410.

7. R. F. Wegman, W. C. Hamilton, and M. J. Bodnar, "A Study of Environmental Degradation of Adhesive Bonded Structures in Army Helicopters," Non-Metallic Materials Selection, Application, and Environmental Effects, National SAMPE Technical Conference Series 1972, pp 425-432.

8. R. Seago, "Cyclic Creep Studies of Adhesives," Aerospace Adhesives and Elastomers, National SAMPE Technical Conference Series 1970, pp 135-144.

9. E. J. Ripling, H. T. Corten, and S. Mostovoy, "Fracture Mechanics: A Tool for Evaluating Structural Adhesives," Aerospace Adhesives and Elastomers, National SAMPE Technical Conference Series 1970, pp 259-272.

10. E. J. Ripling, C. Bersch, and S. Mostovoy, "Stress Corrosion Cracking of Adhesive Joints," Aerospace Adhesives and Elastomers, National SAMPE Technical Conference Series 1970, pp 287-299.

11. R. B. Krieger, Jr, "Advances in the Corrosion Resistance of Bonded Structures," Aerospace Adhesives and Elastomers, National SAMPE Technical Conference Series 1970, pp 549-560.

12. R. H. Greer, "Corrosion Resistant Adhesive Bonding," Aerospace Adhesives and Elastomers, National SAMPE Technical Conference Series 1970, pp 561-570.

13. F. D. Swanson and N. W. Gregornik, "The Evaluation of Adhesives by Underground Exposure in Extreme Environments," Aerospace Adhesives and Elastomers, National SAMPE Technical Conference Series 1970, pp 589-602.

14. E. B. Murphy, "A Weather Stressed Bond," Aerospace Adhesives and Elastomers, National SAMPE Technical Conference Series 1970, pp 603-608.

15. R. F. Wegman and M. J. Bodnar, "Durability of Bonded Titanium Joints Increased by New Process Treatments," New Horizons in Materials and Processing, Science of Advanced Materials and Process Engineering Series, Vol 18, April 1973, pp 378-385.

16. J. E. Lohr, "Factors Affecting the Survivability of Stressed Bonds in Adverse Environments," New Horizons in Materials and Processing, Science of Advanced Materials and Process Engineering Series, Vol 18, April 1973, pp 418-426.

17. M. J. Bodnar and R. F. Wegman, "Effect of Outdoor Aging on Unstressed Adhesive-Bonded Aluminum to Aluminum Lap Shear Joints," Materials and Processes for the 1970's, Science of Advanced Materials and Process Engineering Series, Vol 15, April 1969.

18. R. F. Wegman, M. C. Ross, S. A. Slota, and E. S. Duda, "Evaluation of the Adhesive Bonding Processes Used in Helicopter Manufacture. Part 1, Durability of Adhesive Bonds Obtained as a Result of Processes Used in the UH-1 Helicopter," Technical Report 4186, Picatinny Arsenal, Dover, NJ, September 1971.

19. R. F. Wegman and S. A. Slota, "Evaluation of the Adhesive Bonding Processes Used in Helicopter Manufacture Part 5, Degradation Studies in Bonded Sandwich Panels," Technical Report 4432, Picatinny Arsenal, Dover, NJ, December 1972.

20. R. F. Wegman, S. A. Slota, and W. C. Tanner, "Effects of Varying Processing Parameters in the Fabrication of Adhesive Bonded Structures, Part XIX Durability of Epoxy Bonds to Aluminum Alloys," Technical Report 4483, Picatinny Arsenal, Dover, NJ, June 1973.

21. R. F. Wegman and M. J. Bodnar, "Structural Adhesive Bonding of Titanium - Superior Surface Preparation Techniques, "SAMPE Quarterly, Vol 5, No. 1, October 1973, pp 28-36.

22. R. F. Wegman and S. A. Slota, "Evaluation of the Adhesive Bonding Processes Used in Helicopter Manufacture, Part 6, Evaluation of Improved Titanium Surface Preparation by Bond Durability Studies," Technical Report 4476, Picatinny Arsenal, Dover, N., March 1973.

23. R. F. Wegman, "Durability of Adhesive-Bonded Aluminum Joints, Technical Report 4169, Picatinny Arsenal, Dover, NJ, June 1971.

24. R. F. Wegman and S. A. Slota, "Development and Evaluation of the RAYSTAN Outdoor Fatigue Tester," Technical Report 4406, Picatinny Arsenal, Dover, NJ, November 1972.

25. M. J. Barbarisi, B. R. Chisholm, and P. J. Kisatsky, "Evaluation of the Adhesive Bonding Processes Used in Helicopter Manufacture, Part 4, Nondestructive Inspection of Adhesive Bonds Using Holographic Techniques," Technical Report 4419, Picatinny Arsenal, Dover, NJ, October 1972.

26. ASTM D2919-71 "Recommended Practice for Determining Durability of Adhesive Joints Stressed in Shear by Tension Loading," Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, PA, 1971.

27. A. W. Bethume, "Durability of Bonded Aluminum Structure," paper presented at the 19th National SAMPE Symposium, Los Angeles, 23-25 April 1974.

28. W. D. Sell, "Some Analytical Techniques for Durability Testing of Structural Adhesives," paper presented at the 19th National SAMPE Symposium, Los Angeles, CA, 23-25 April 1974.

29. A. D. Lajoie and R. A. Seago, "Evaluation of Three Bonding Surface Preparation Methods for 6A1-4V Titanium," paper presented at the 19th National SAMPE Symposium, Los Angeles, CA, 23-25 April 1974.

30. S. A. Slota and R. F. Wegman, "Durability of Adhesive Bonds to Various Adherends," Technical Report 4917, Picatinny Arsenal, Dover, NJ, June 1976.

31. R. F. Wegman, S. A. Slota, M. C. Ross, E. A. Garnis, and E. S. Duda, "Durability of Adhesive-Bonded Metallic Joints," Technical Report 4707, Picatinny Arsenal, Dover, NJ, December 1974.

32. R. F. Wegman, S. A. Slota, M. C. Ross, and E. A. Garnis, "The Effect of Environmental Exposure on the Endurance of Bonded Joints in Army Helicopters," Technical Report 4744, Picatinny Arsenal, Dover, NJ, May 1974.

33. R. F. Wegman, M. C. Ross, E. A. Garnis, and S. A. Slota, "New Bonding Systems for Depot Maintenance of Aircraft Honeycomb Structures, Part 1, Preliminary Evaluation of Ten Structural Adhesives," Technical Report 4810, Picatinny Arsenal, Dover, NJ, November 1975.

34. R. F. Wegman, M. C. Ross, and E. A. Garnis, "New Bonding Systems for Depot Maintenance of Aircraft Honeycomb Structures, Part III, Evaluation of Processing Variables on the Durability of Bonded Joints," Technical Report 4922, Picatinny Arsenal, Dover, NJ, to be published.

35. D. W. Levi, R. F. Wegman, M. C. Ross, and E. A. Garnis, "Use of Hot Water Aging for Estimating Lifetime of Adhesives, SAMPE Quarterly, Vol 7, No. 3, April 1976, pp 1-4.

36. John E. Freund, Mathematical Statistics, Prentice-Hall, 1962.

Table 1. Adhesives

Code	Type
A	Supported, modified epoxy film
B	Supported, modified epoxy film
C	Supported, modified epoxy film
D	Supported, modified epoxy film
E	Unsupported, modified epoxy film
F	Supported, modified epoxy film
G	Supported, modified epoxy film
H	Supported, modified epoxy film
I	Supported, modified epoxy film
J	Supported, modified epoxy film
K	Supported, modified epoxy film
L	Supported, modified epoxy film

Table 2. Comments on data plots

Figure Number	Comments
1	The prediction curve is almost identical to the stressed durability curve, with a slightly different slope.
2	The slope of the prediction curve is slightly different than the slope of the stressed durability curve.
3	The predicted time-to-failure is slightly lower than the actual time-to-failure.
4	The curves are almost identical.
5	Same as 3.
6	The prediction curve indicates longer time-to-failure at high loads and shorter time-to-failure at low loads than the stressed durability curve.
7	Same as 3.
8	Same as 3.
9	The prediction curve indicates shorter time-to-failure at high loads and longer time-to-failure at low loads than the stressed durability curve.
10	Same as 6.
11	Same as 2.
12	The prediction and stressed durability curves are identical.
13	Same as 3.
14	Same as 4.
15	Same as 2.

Table 2 (Continued)

Figure Number	Comments
16	Same as 4.
17	Same as 2.
18	Same as 2.
19	Same as 9.
20	Same as 9.
21,22,23	Stressed durability curve not determined; only a prediction curve based on one set of time-to-failure data is shown.

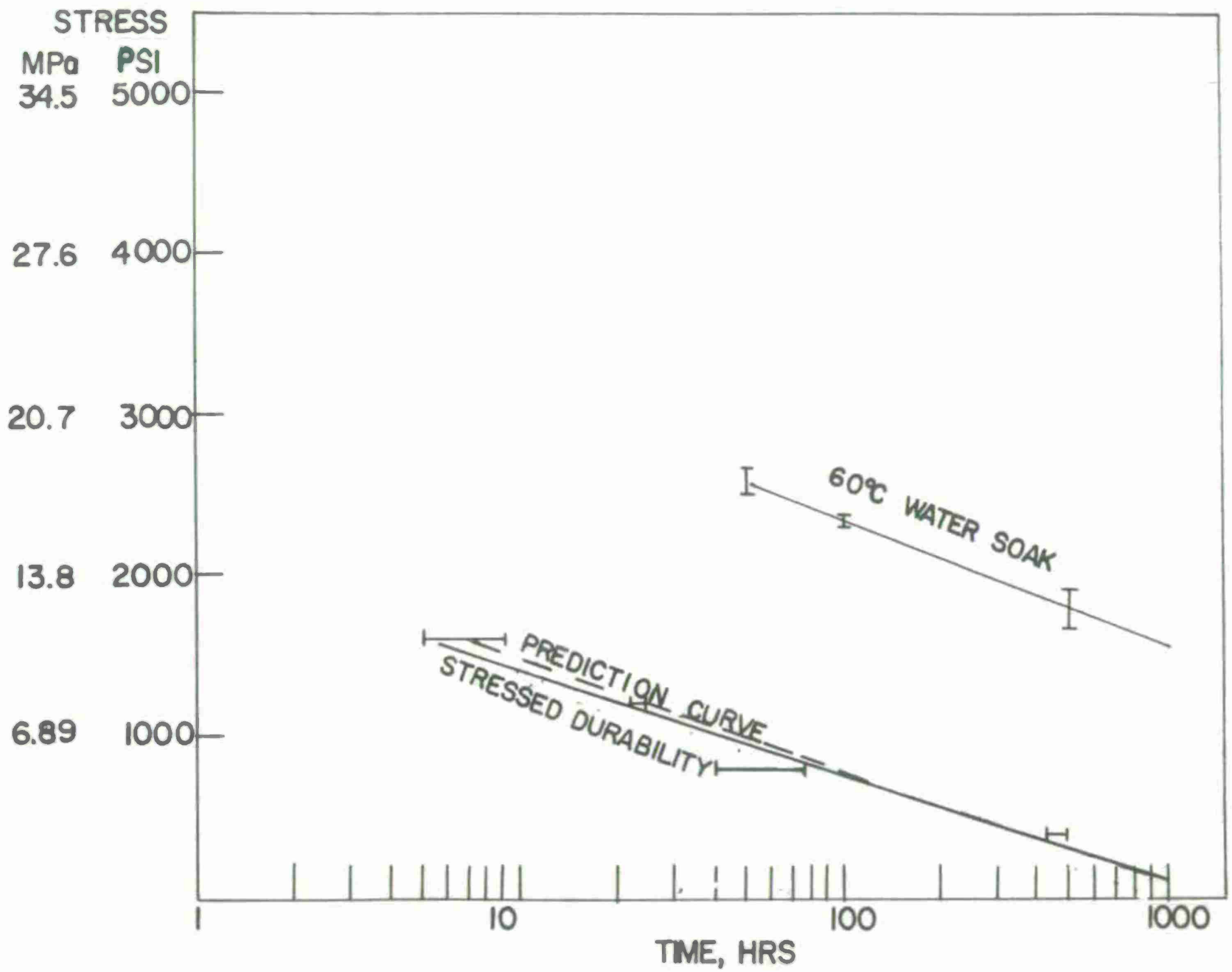

Figure 1. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for FPL etched 2024T3 aluminum alloy joints bonded with adhesive A

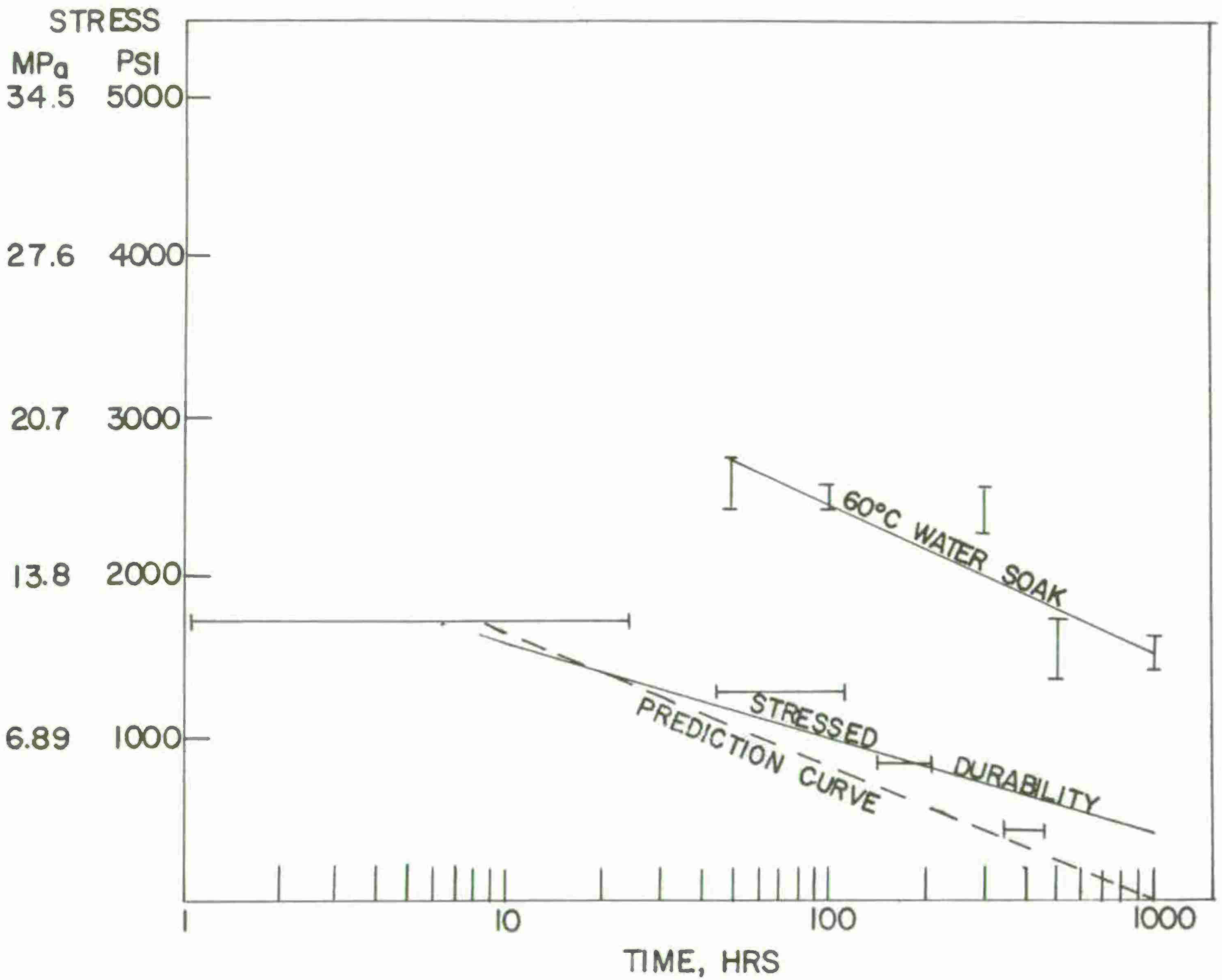

Figure 2. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for anodized 2024T3 aluminum alloy joints bonded with adhesive A

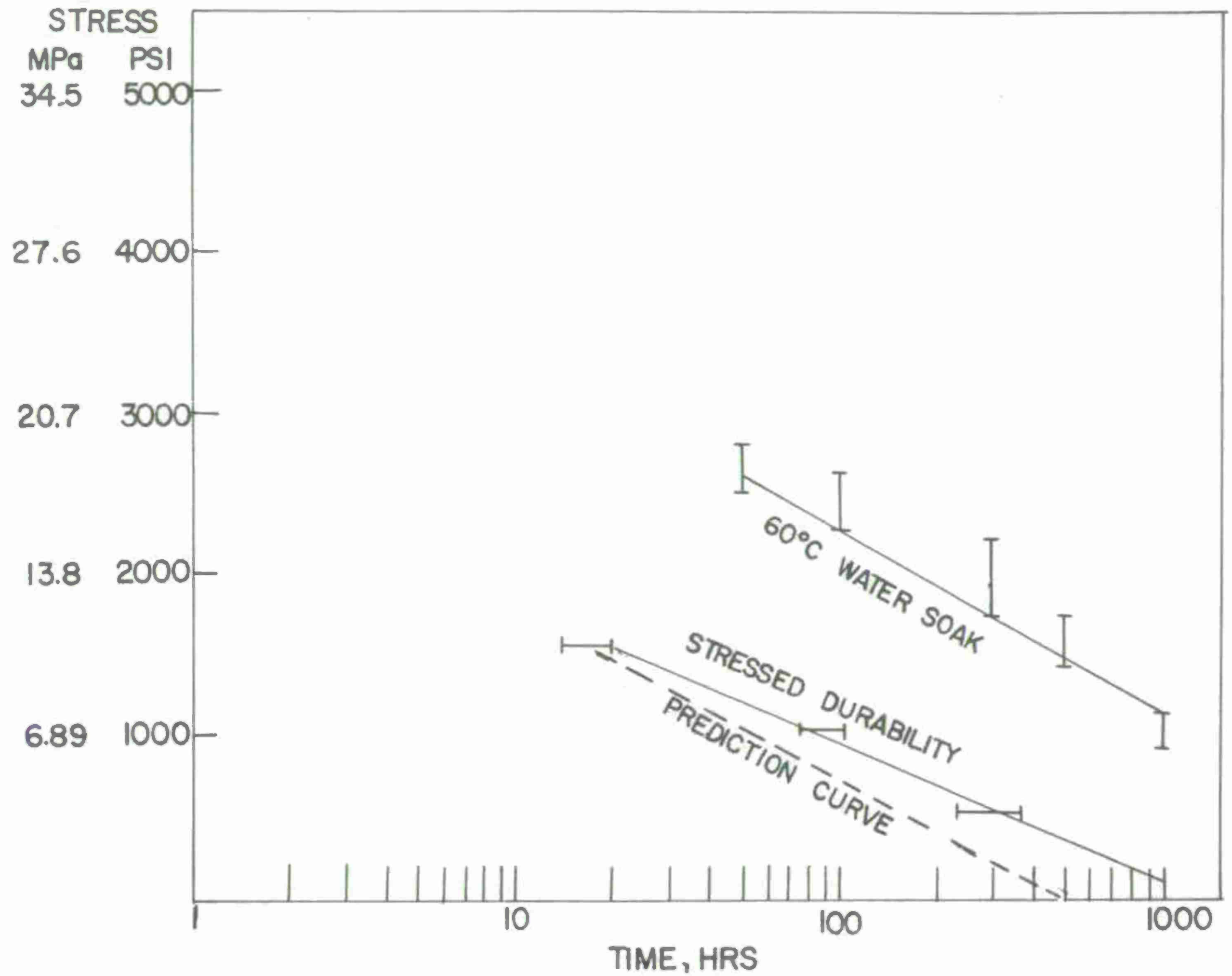

Figure 3. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for etched CP titanium alloy joints bonded with adhesive A

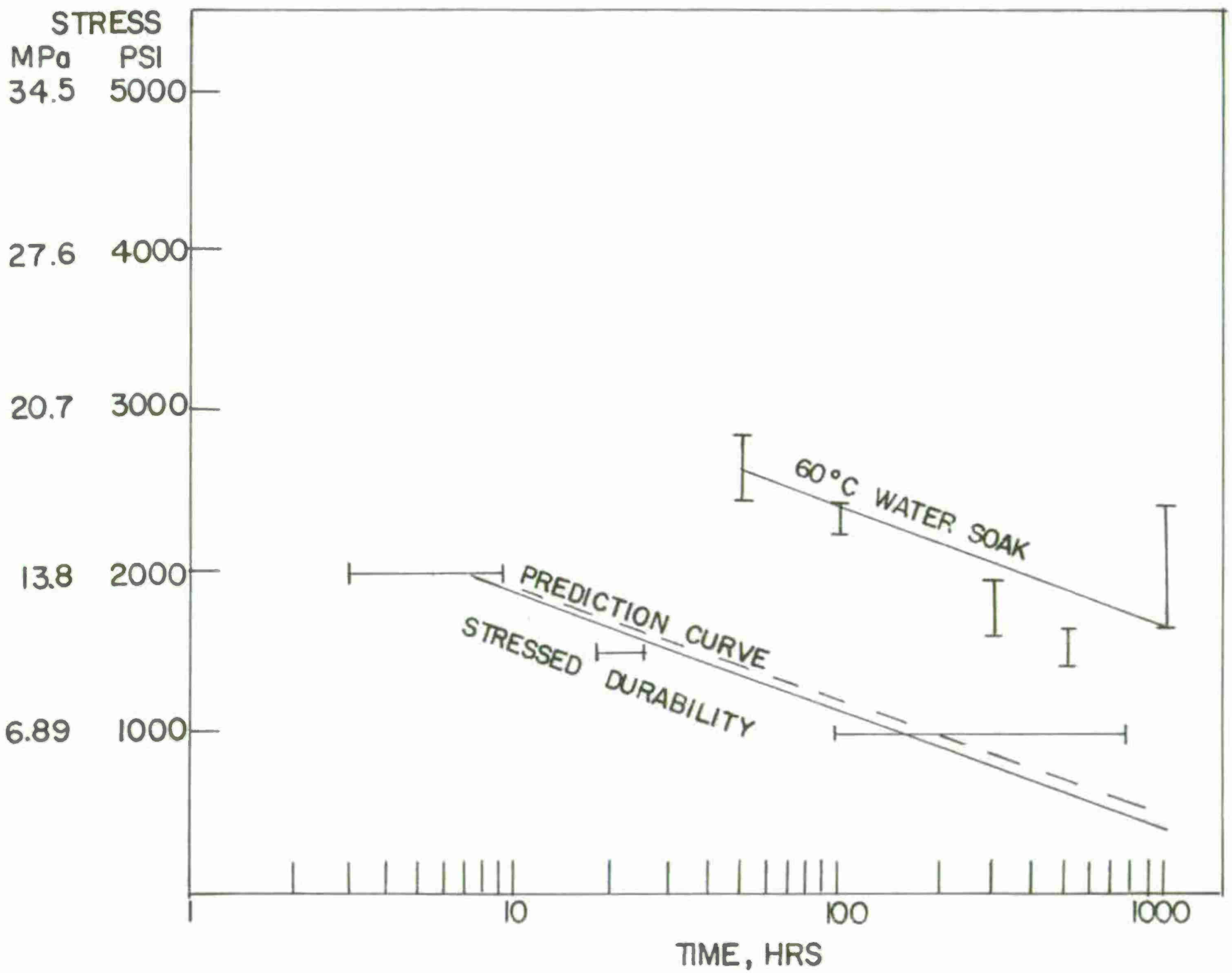

Figure 4. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for etched 6,4 titanium alloy joints bonded with adhesive A

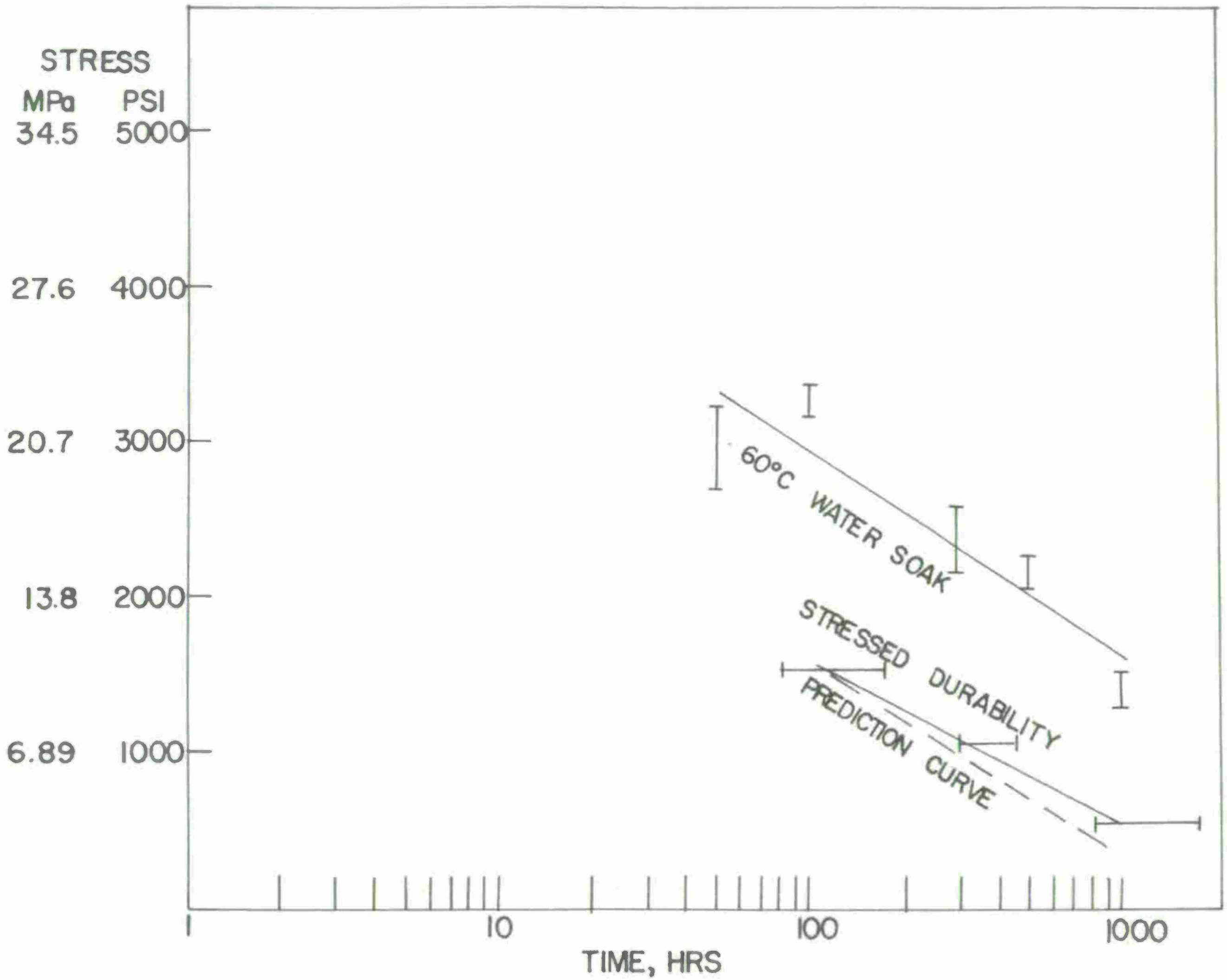

Figure 5. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for etched CP titanium alloy joints bonded with adhesive B

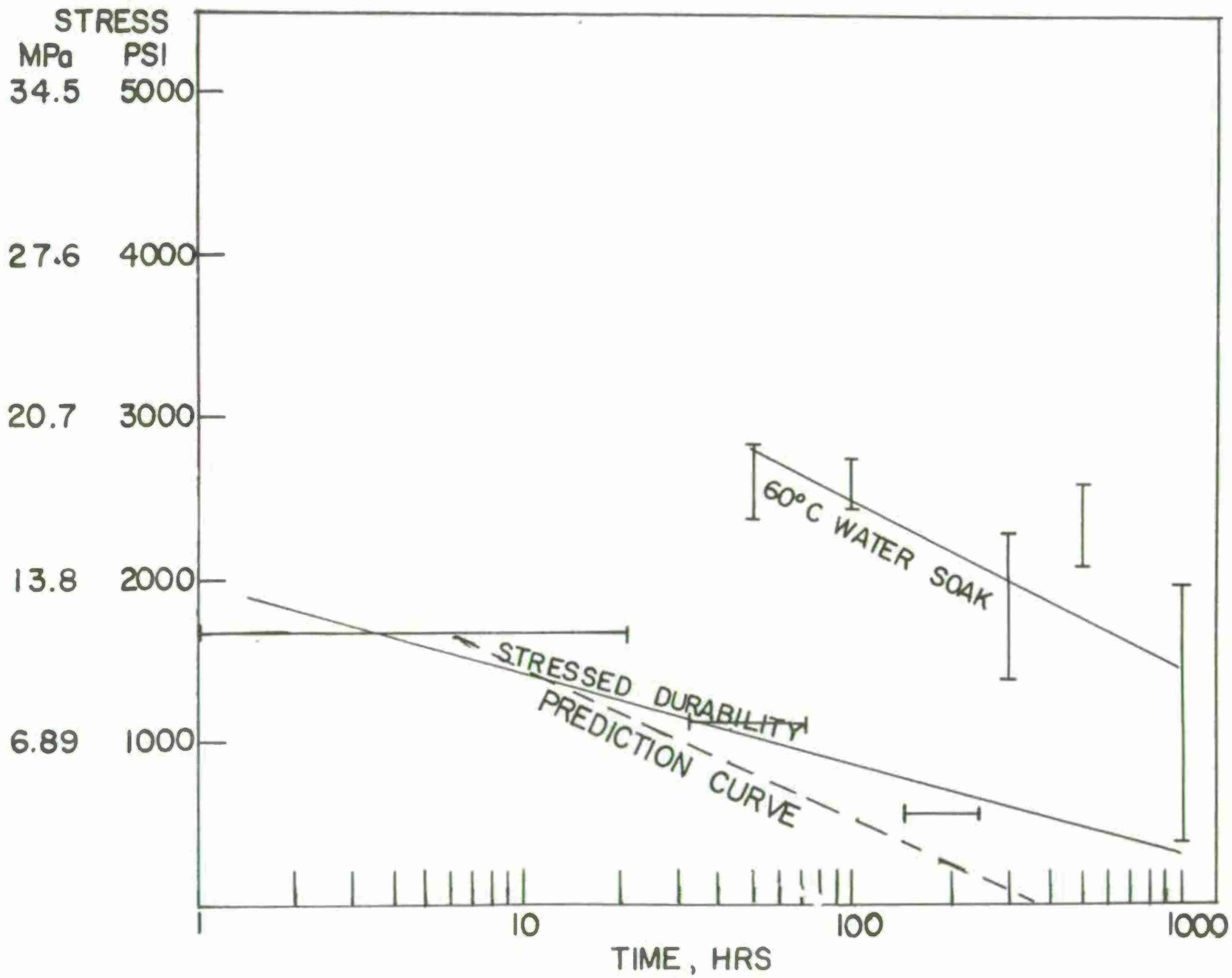

Figure 6. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for etched 6,4 titanium alloy joints bonded with adhesive C

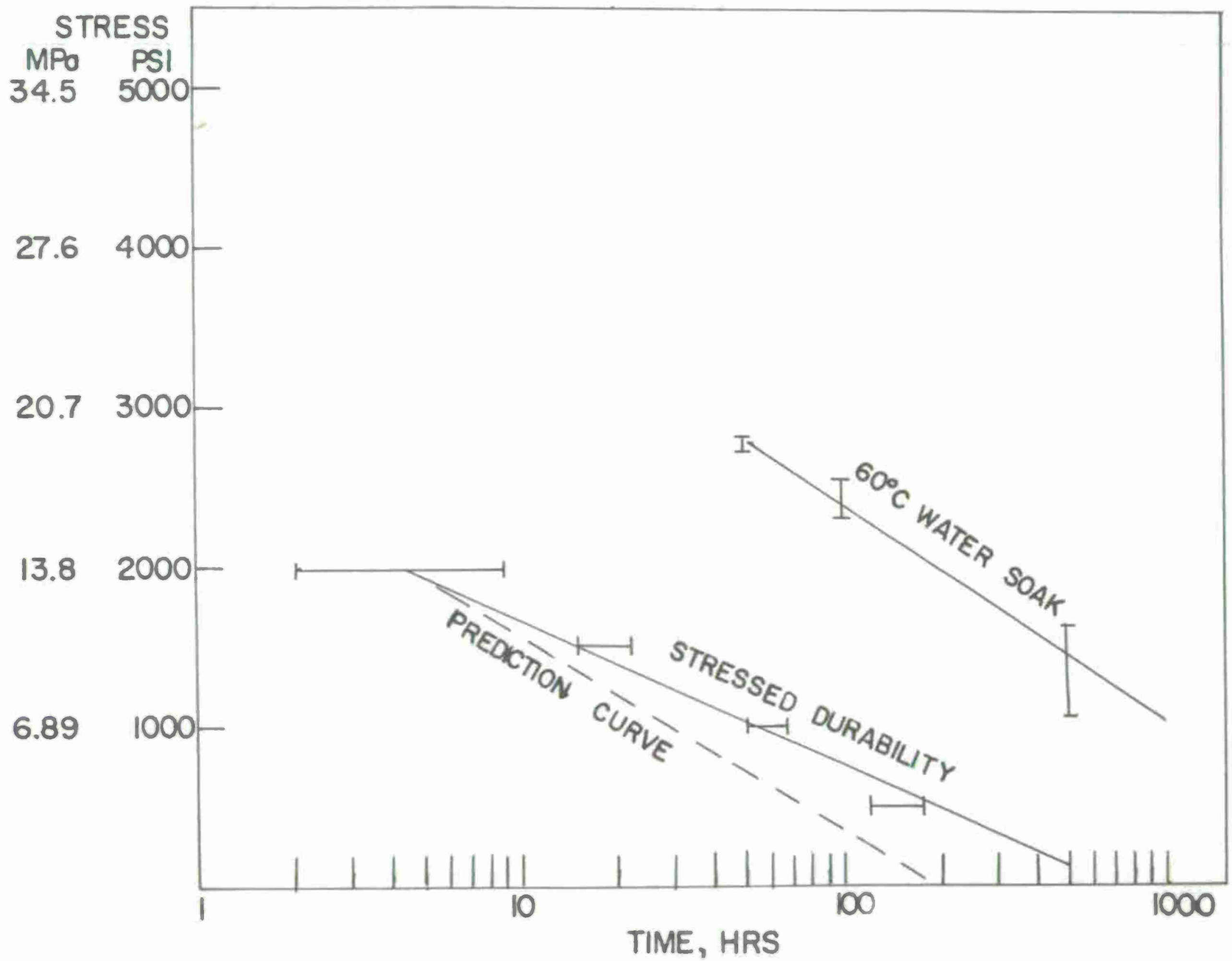

Figure 7. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for FPL etched 2024T3 aluminum alloy joints bonded with adhesive C

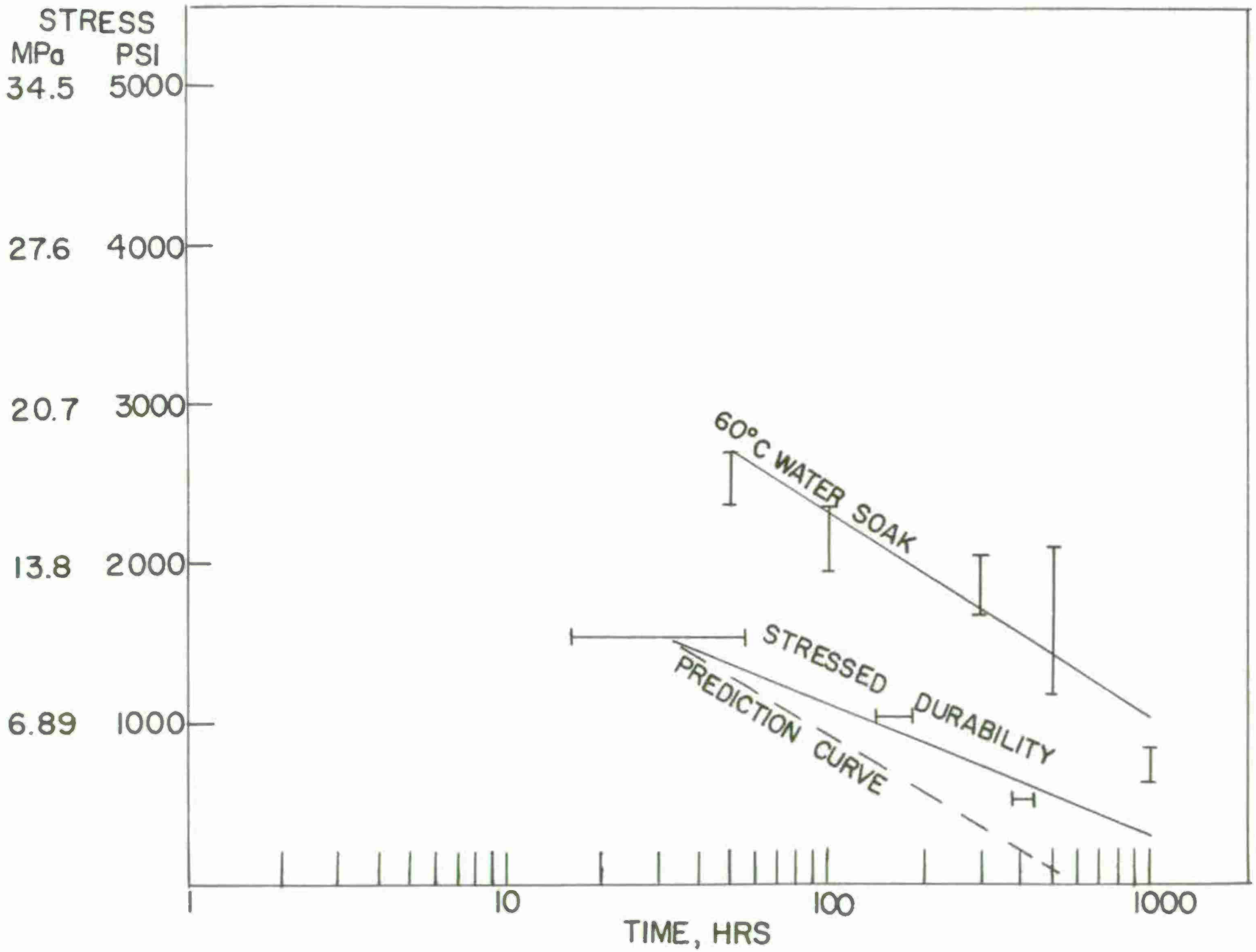

Figure 8. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for etched CP titanium alloy joints bonded with adhesive C

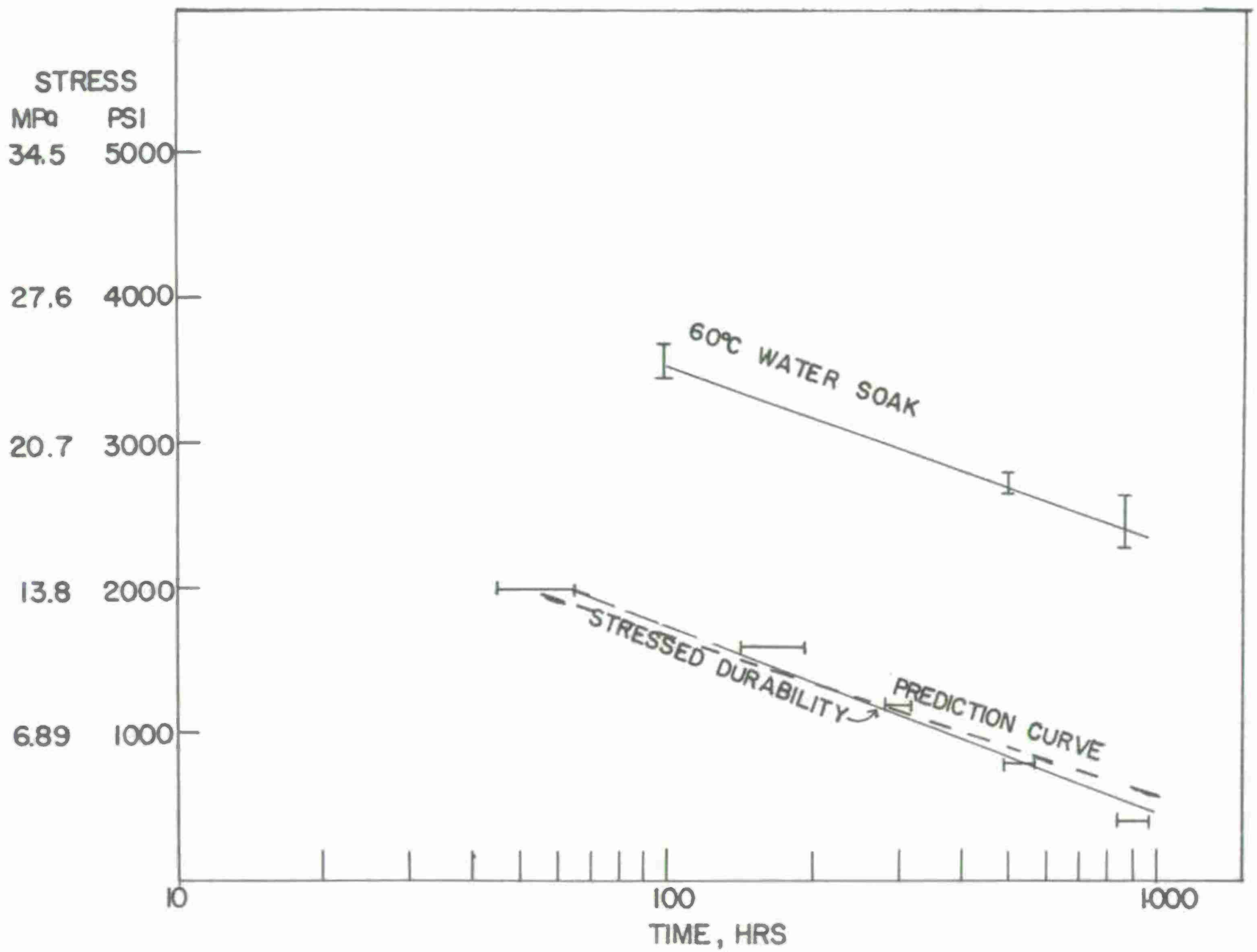

Figure 9. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for etched CP titanium alloy joints bonded with adhesive D

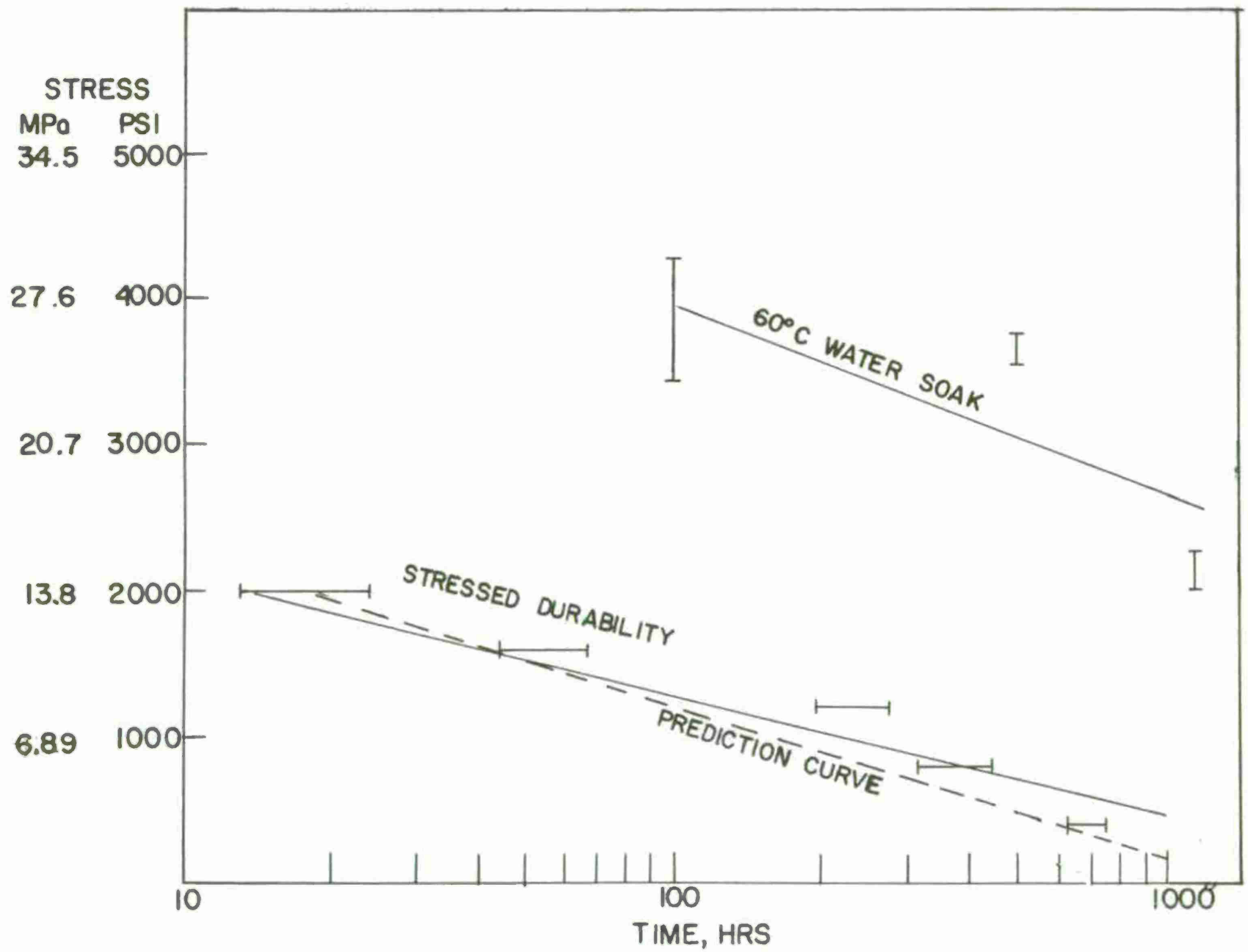

Figure 10. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for anodized 2024T3 aluminum alloy joints bonded with adhesive D

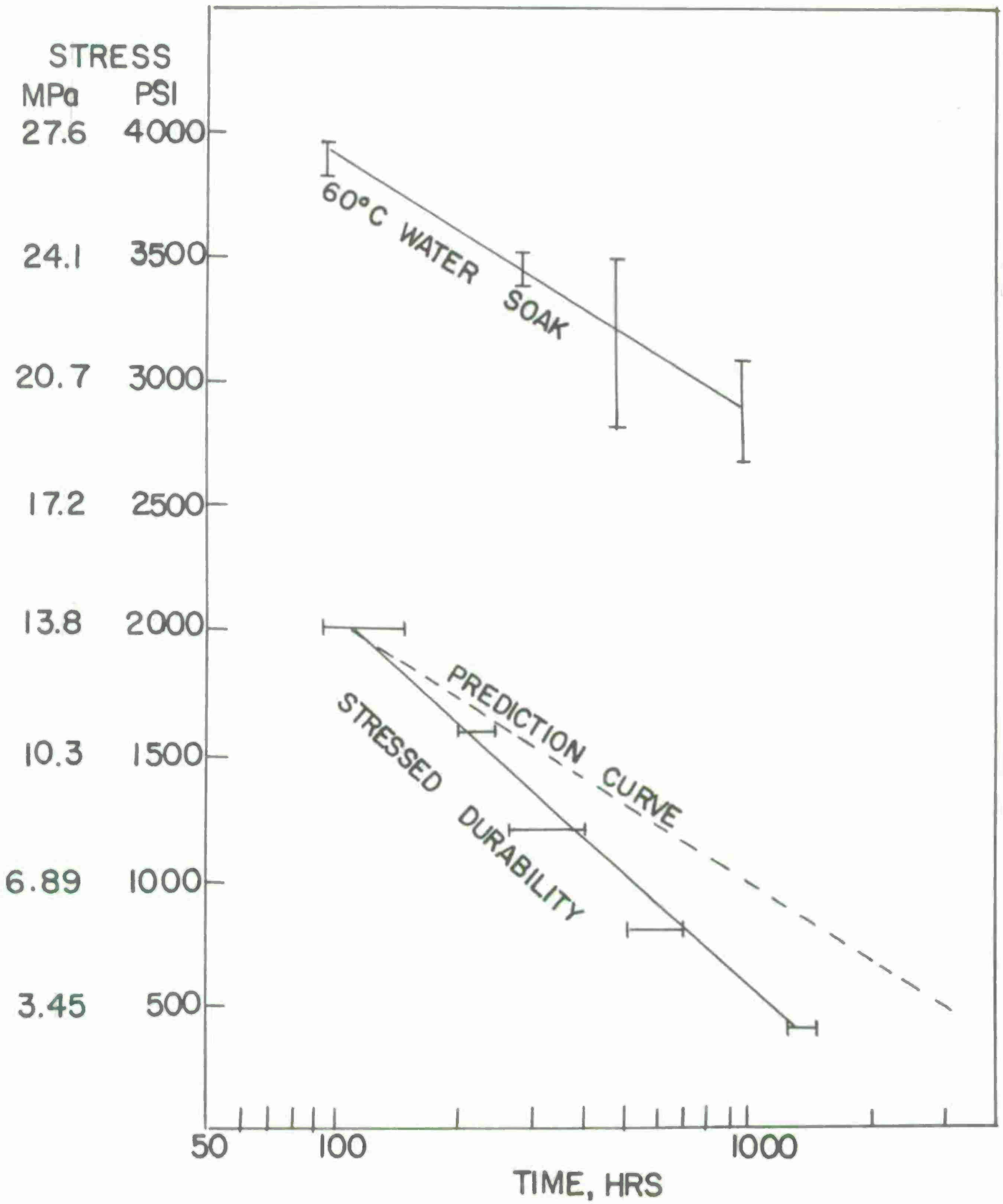

Figure 11. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for FPL etched 2024T3 aluminum alloy joints bonded with adhesive D

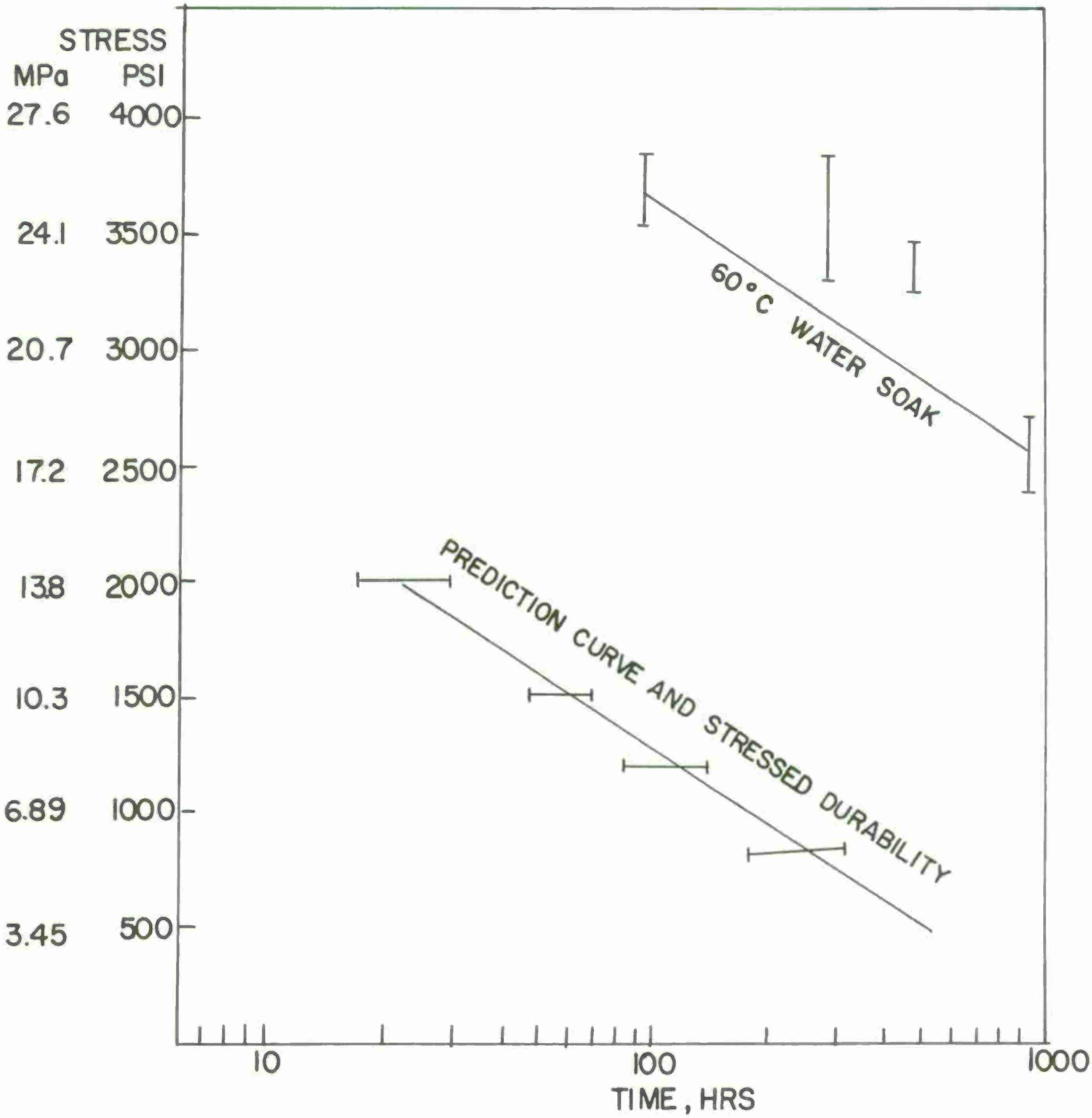

Figure 12. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for FPL etched 2024T3 aluminum alloy joints bonded with adhesive G

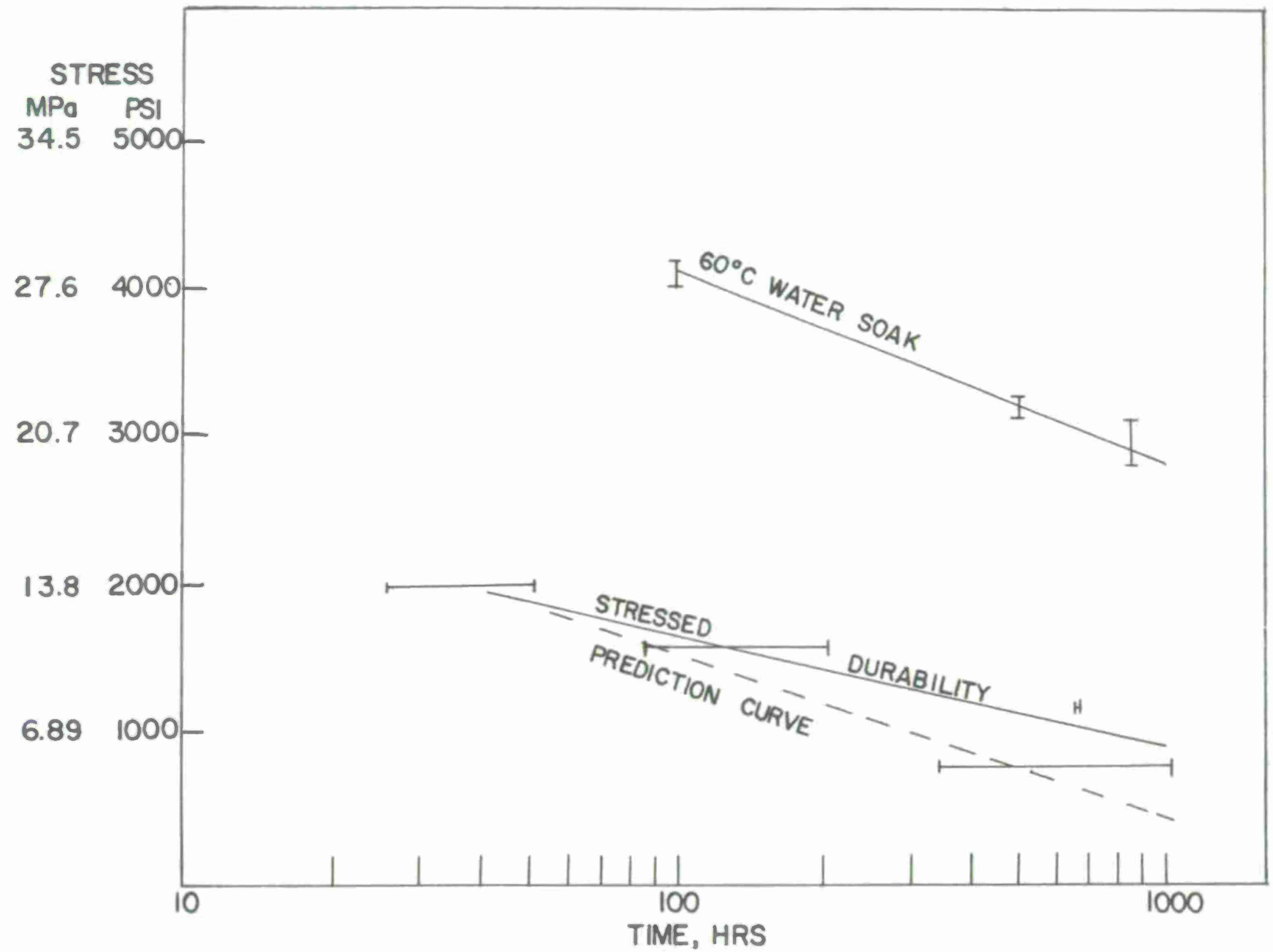

Figure 13. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for etched CP titanium alloy joints bonded with adhesive I

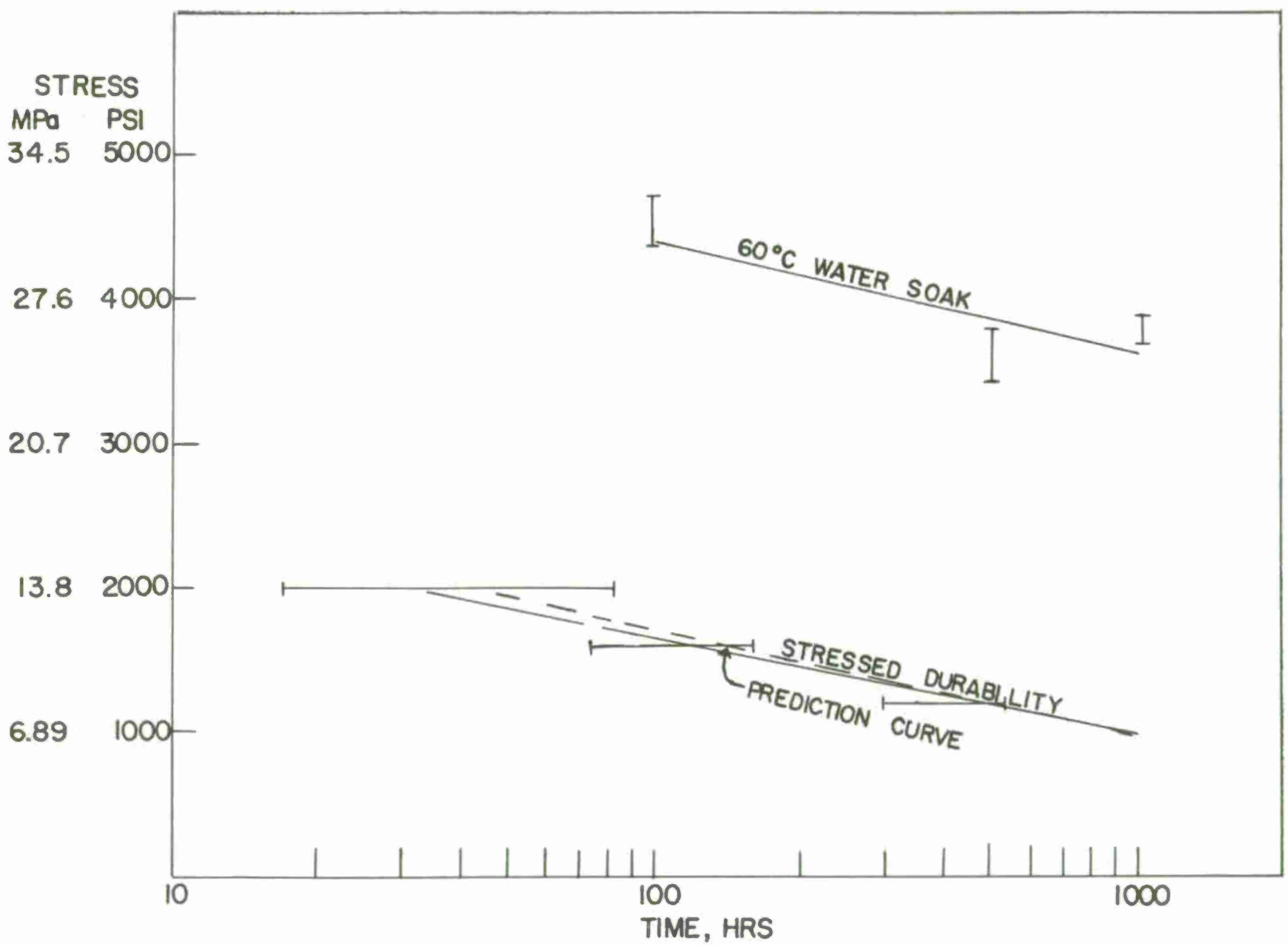

Figure 14. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for anodized 2024T3 aluminum alloy joints bonded with adhesive I

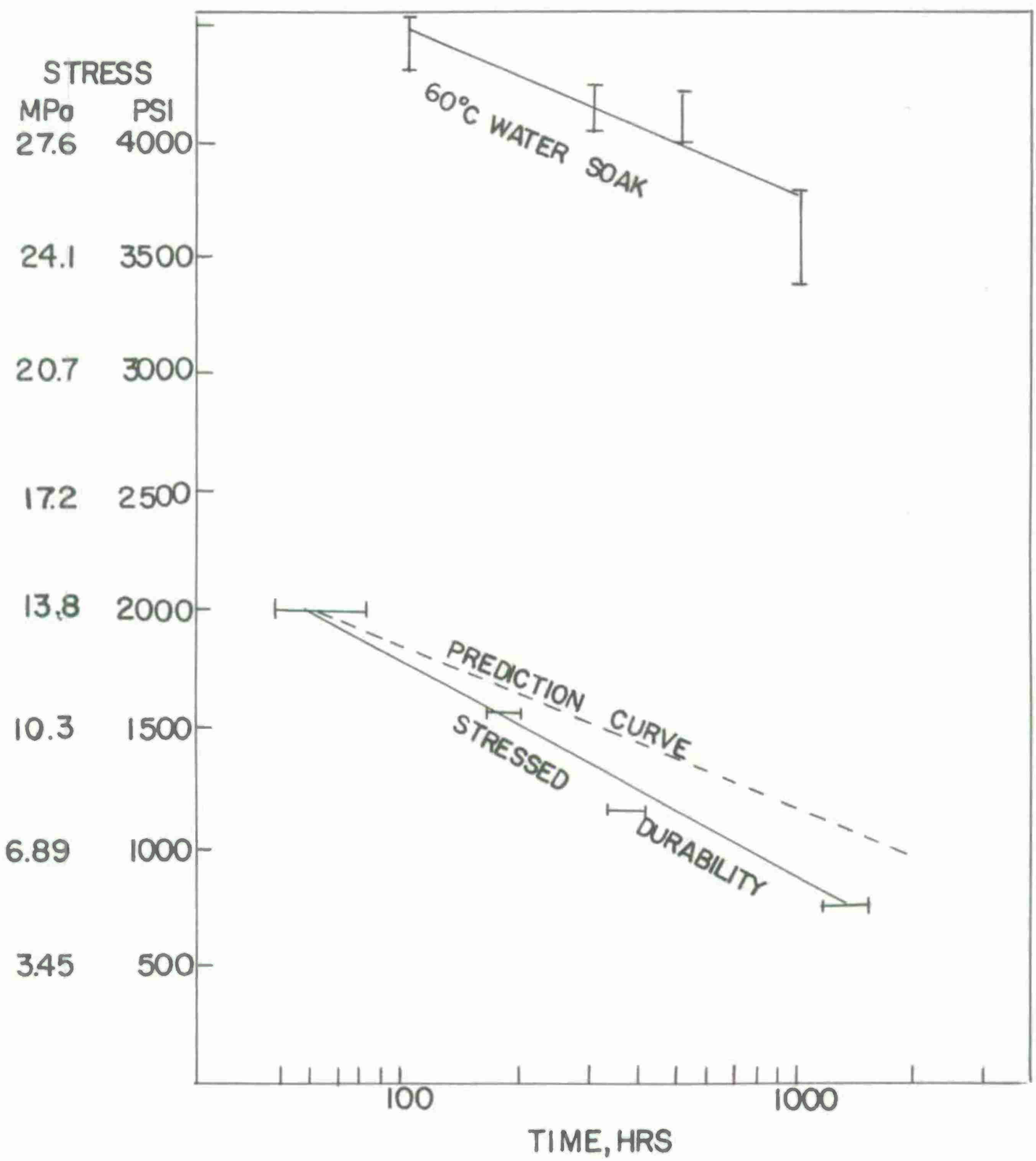

Figure 15. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for FPL etched 2024T3 aluminum alloy joints bonded with adhesive I

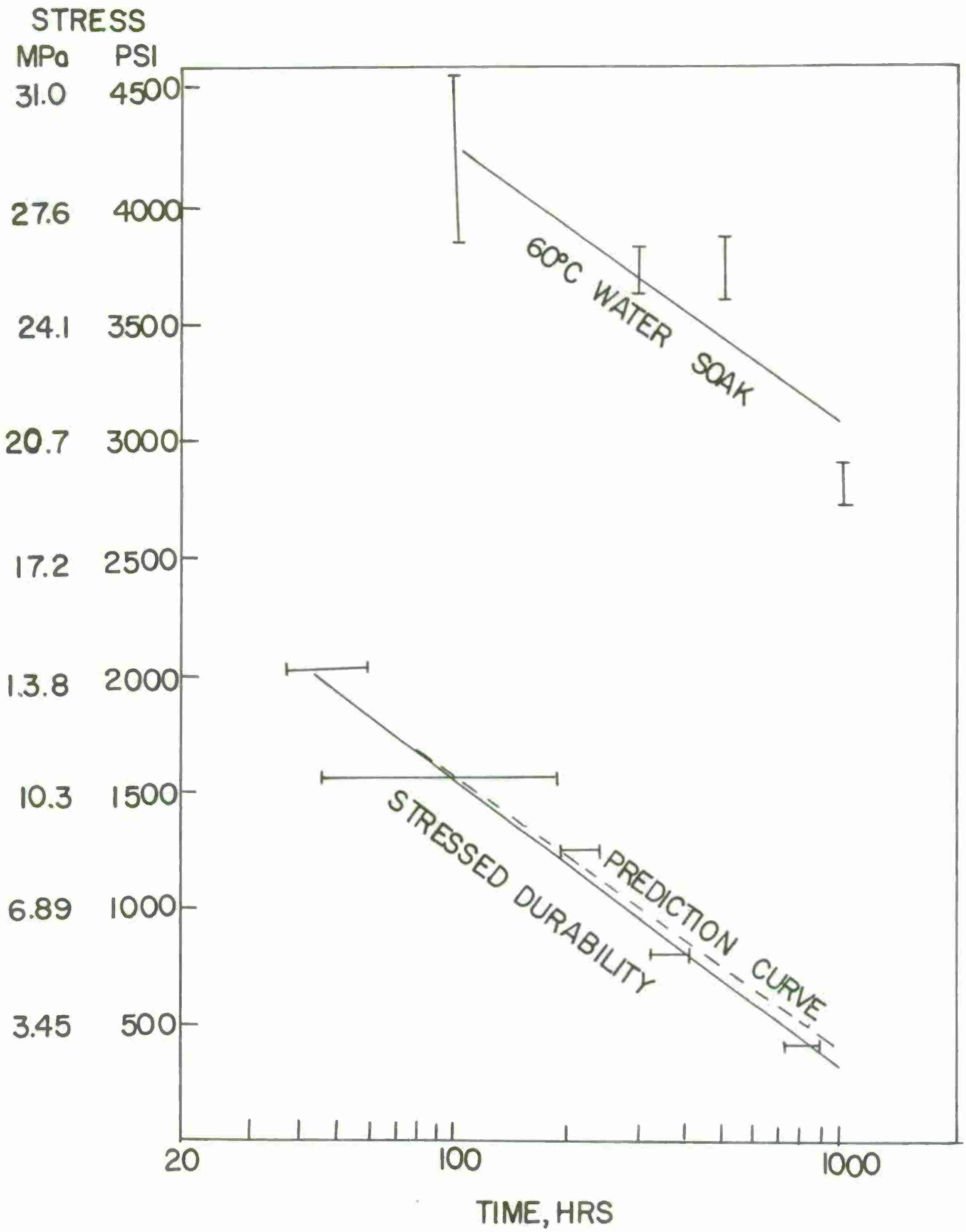

Figure 16. Comparison of 60°C.water-soak residual-strength curves to stressed-durability curves for FPL etched 2024T3 aluminum alloy joints bonded with adhesive J

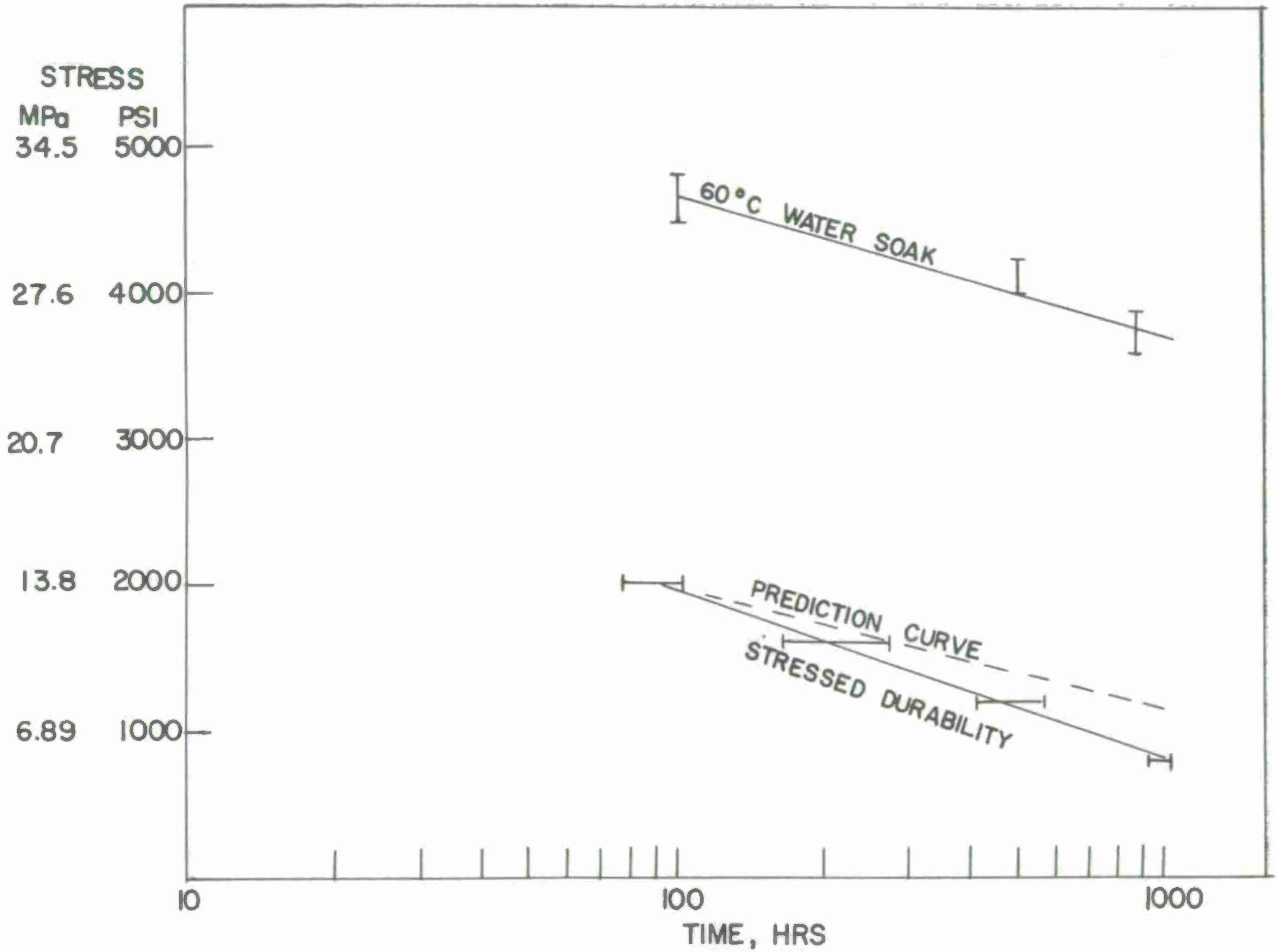

Figure 17. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for etched CP titanium alloy joints bonded with adhesive K

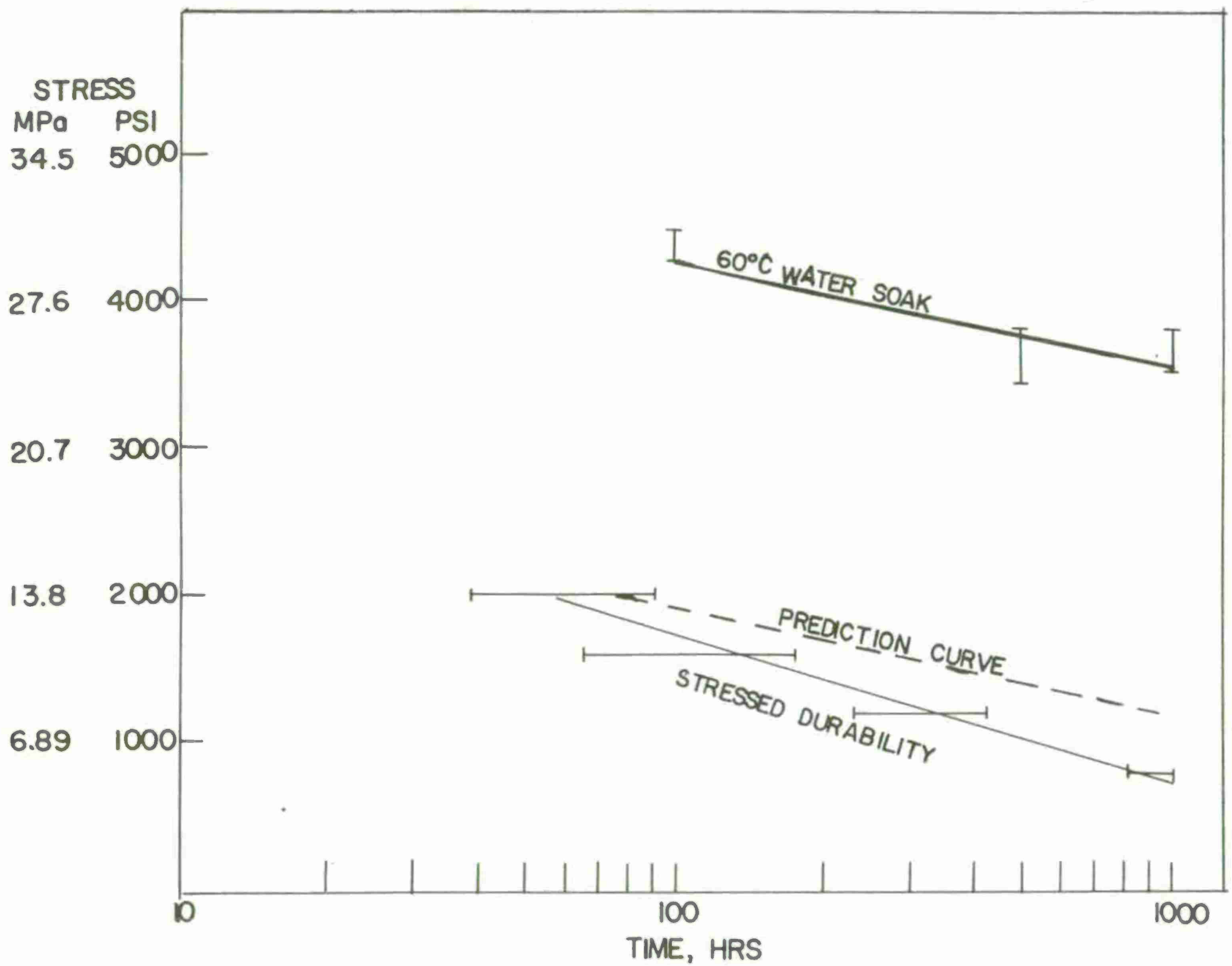

Figure 18. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for anodized 2024T3 aluminum alloy joints bonded with adhesive K

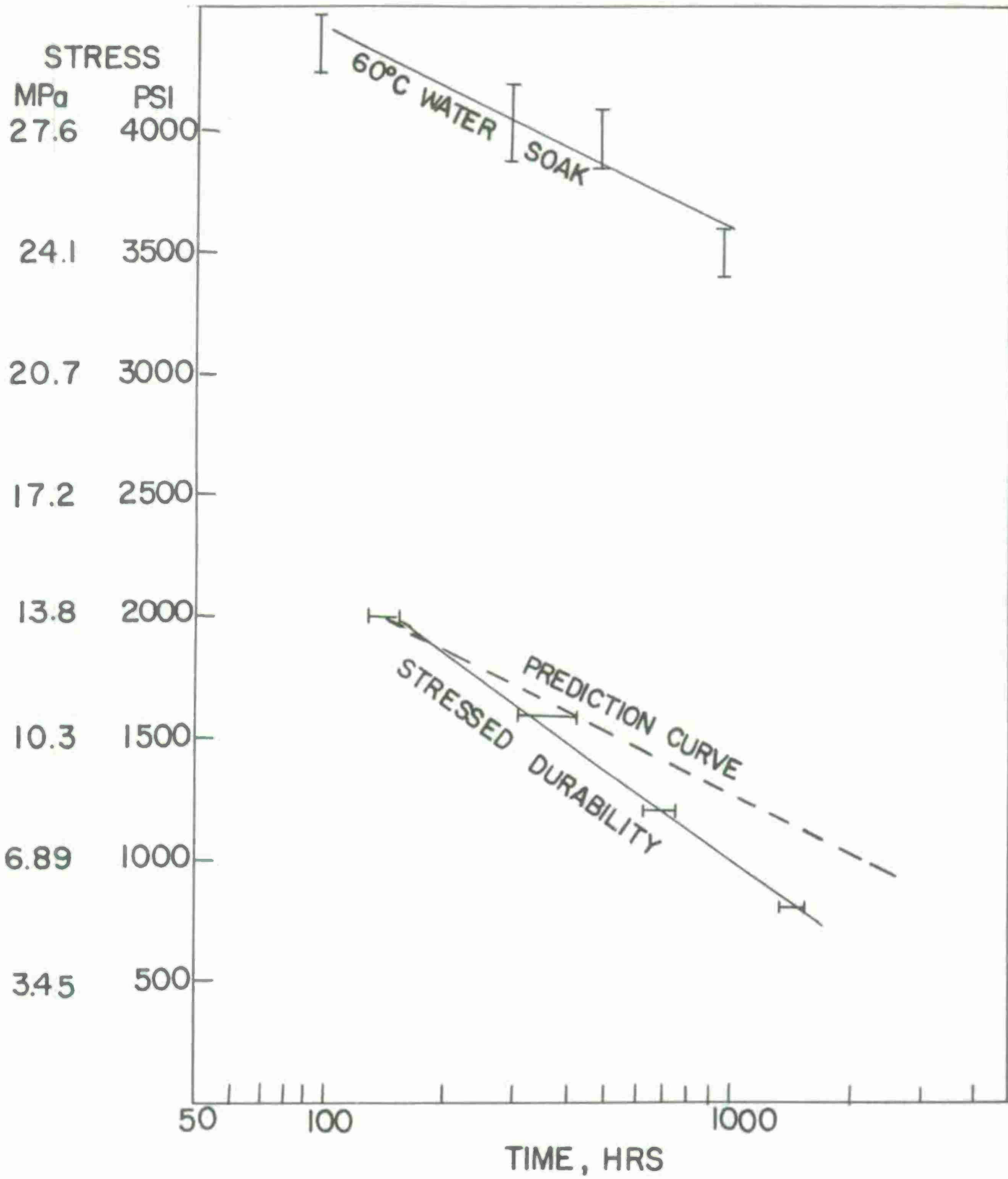

Figure 19. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for FPL etched 2024T3 aluminum alloy joints bonded with adhesive K

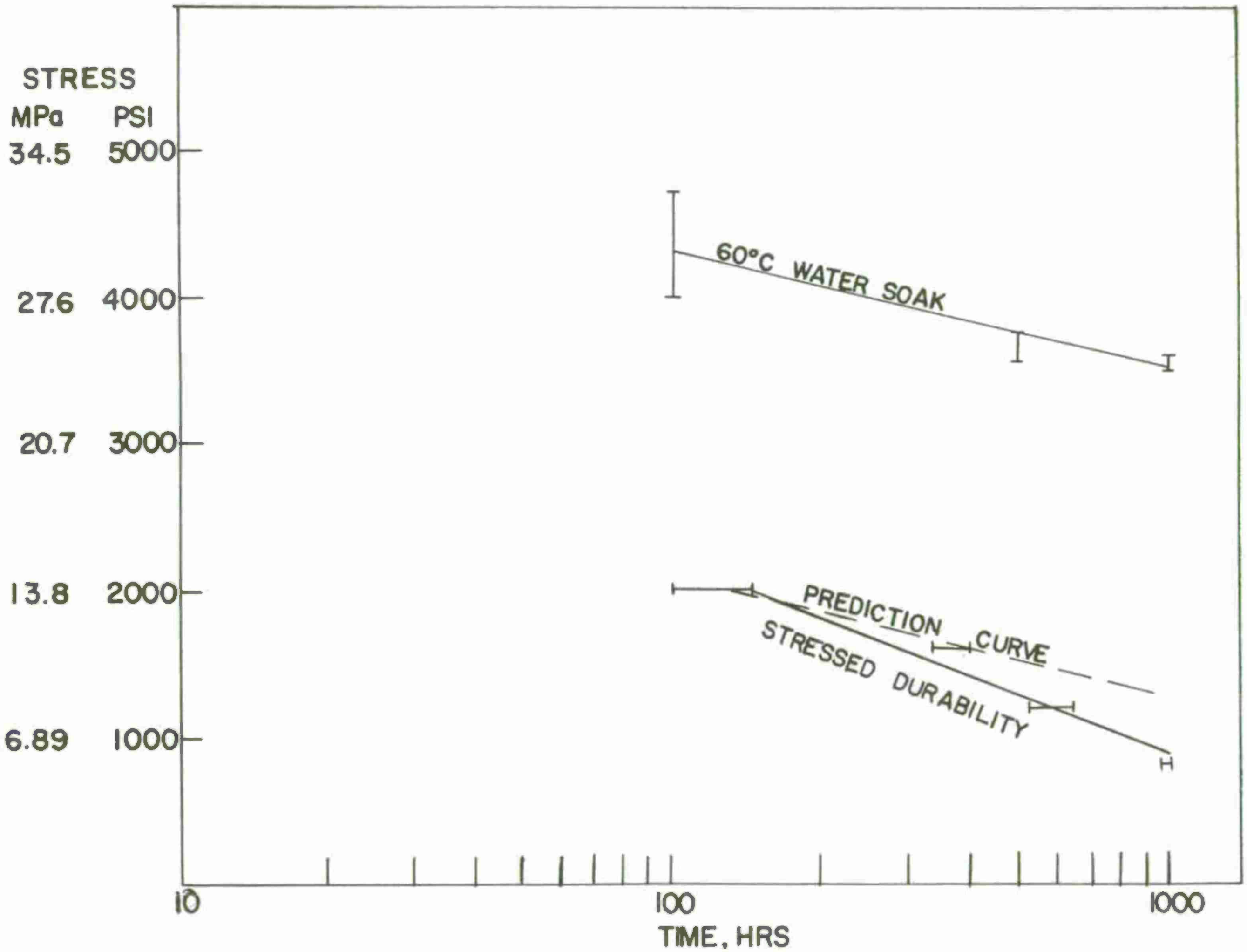

Figure 20. Comparison of 60°C water-soak residual-strength curves to stressed-durability curves for anodized 2024T3 aluminum alloy joints bonded with adhesive L

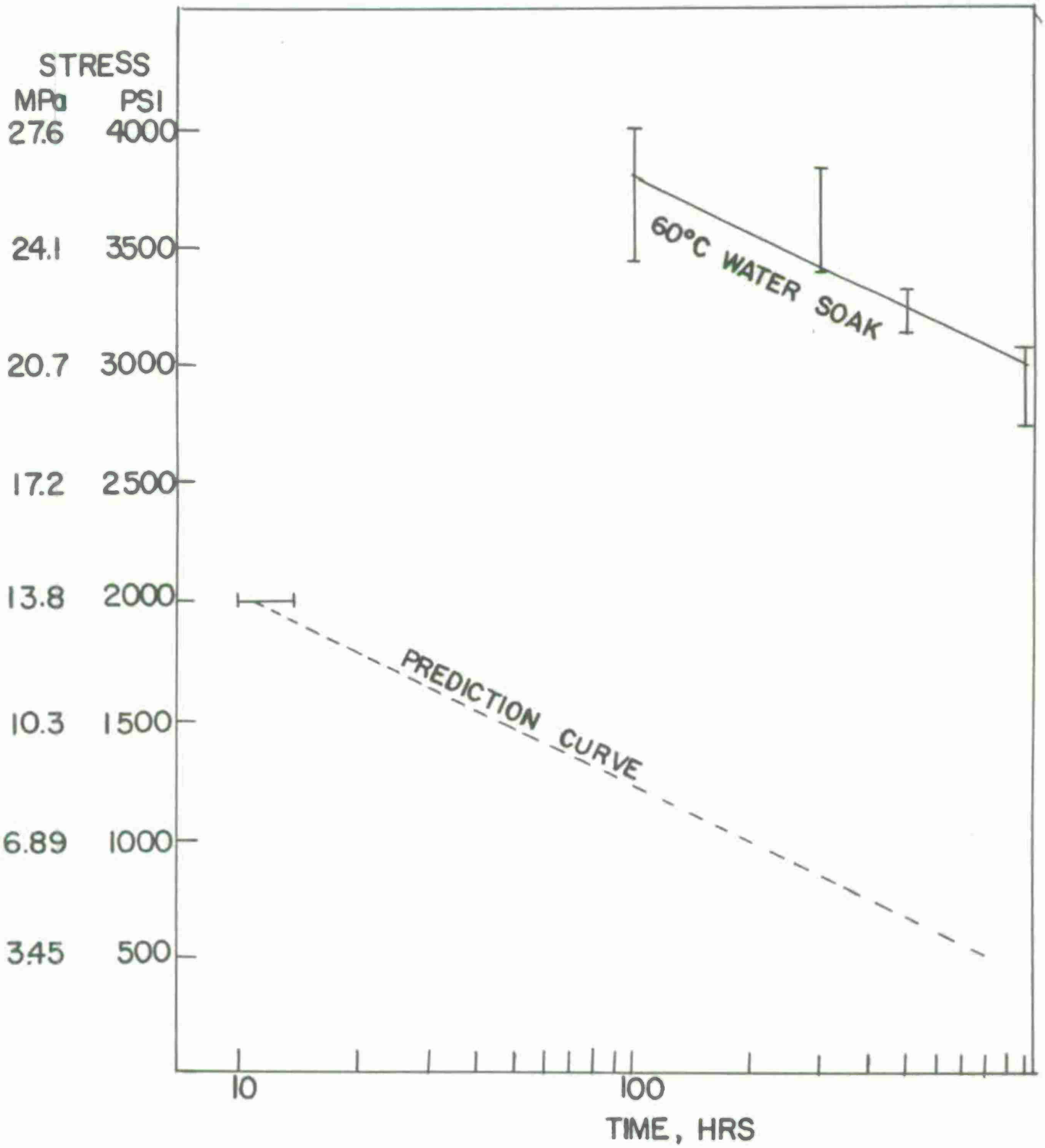

Figure 21. Comparison of 60°C water-soak residual-strength curves to predicted stressed-durability curves for FPL etched 2024T3 aluminum alloy joints bonded with adhesive E

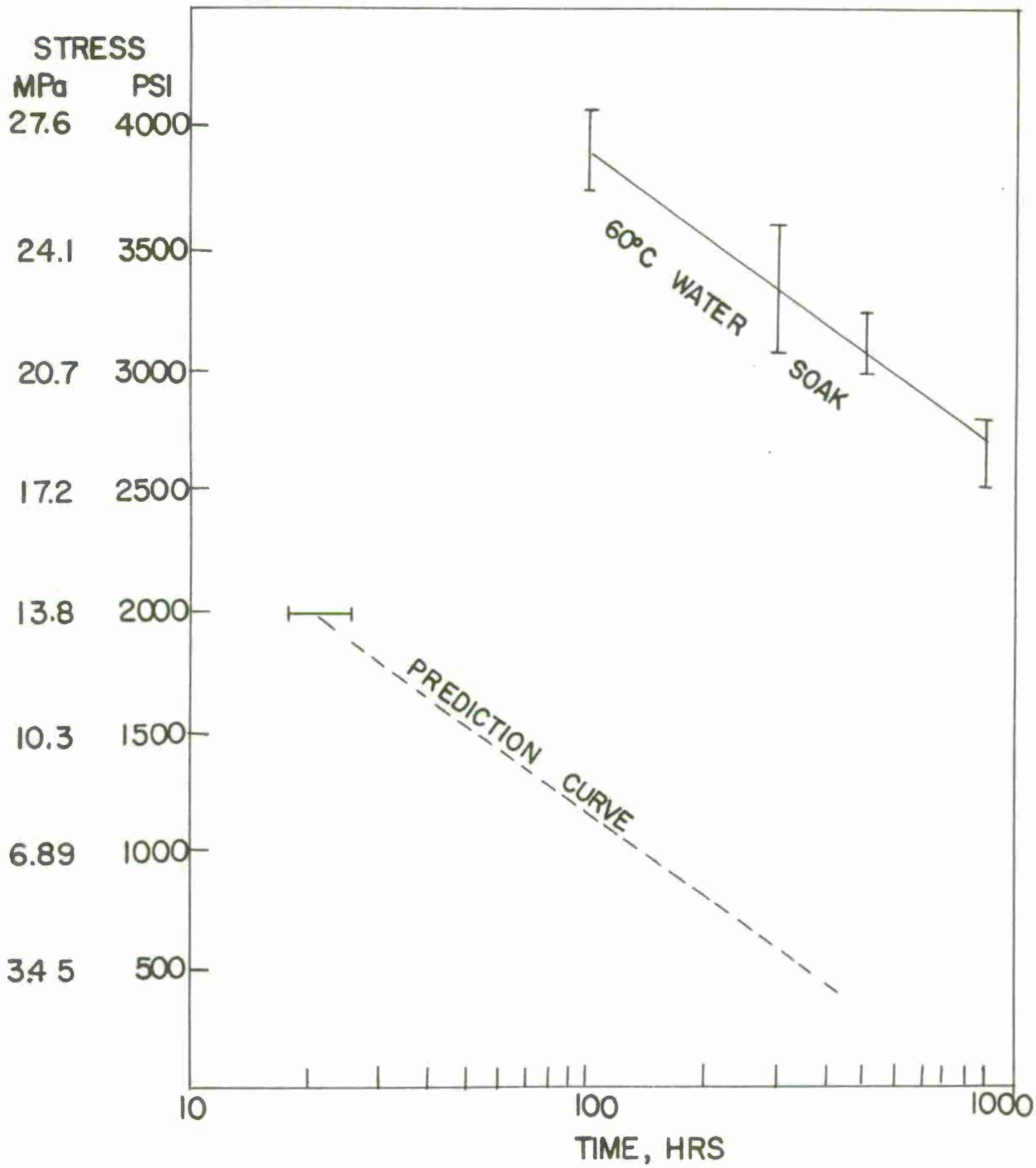

Figure 22. Comparison of 60°C water-soak residual-strength curves to predicted stressed-durability curves for FPL etched 2024T3 aluminum alloy joints bcnded with adhesive F

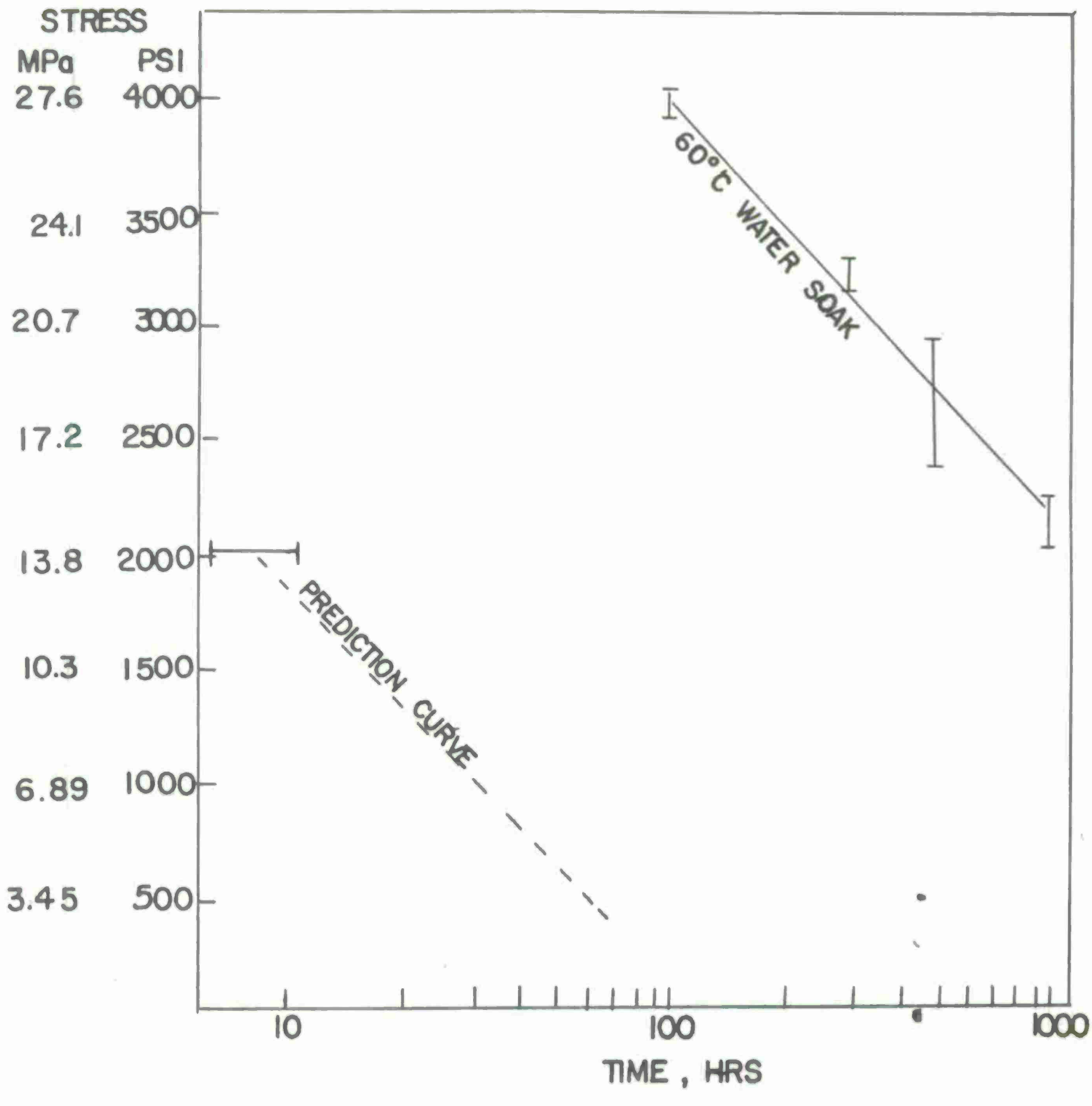

Figure 23. Comparison of 60°C water-soak residual-strength curves to predicted stressed-durability curves for FPL etched 2024T3 aluminum alloy joints bonded with adhesive H

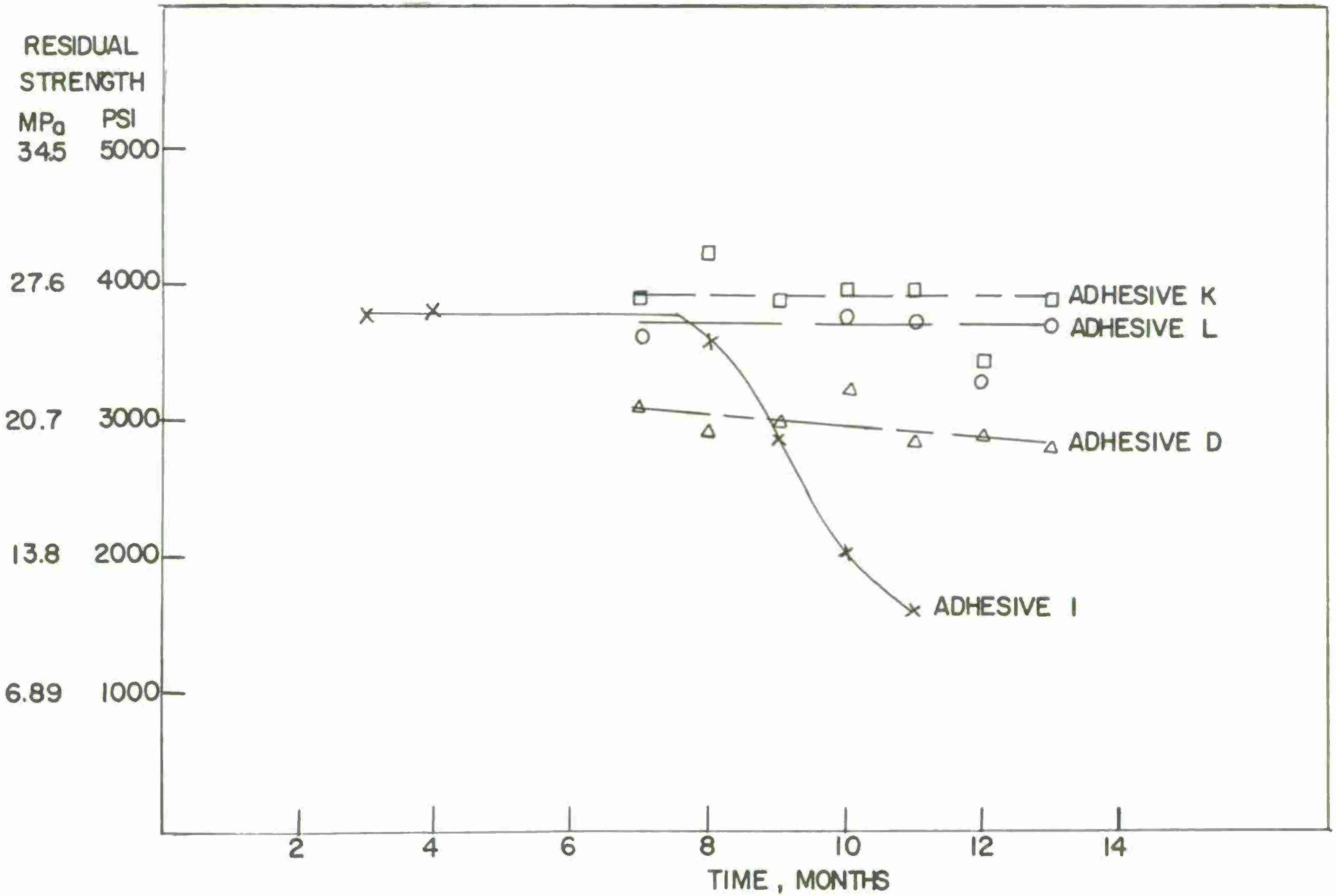

Figure 24. Effect of -20°C storage of the adhesive on the durability of bonds tested by using the 1000 hour, 60°C water-soak residual-strength values

DISTRIBUTION LIST

Commander
US Army Armament Research & Development Command
ATTN: DRDAR-TSS (5)
DRDAR-LCA-OA (15)
DRDAR-LCN (5)
DRDAR-LCU (5)
DRDAR-QA (2)
DRDAR-TSF (2)
DRDAR-QAA
DRDAR-QAN
Dover, NJ 07801

Commander
US Army Materiel Development & Readiness Command
ATTN: DRCPP-PI
DRC-QA
5001 Eisenhower Avenue
Alexandria, VA 22304

Commander
US Army Missile Research & Development Command
ATTN: DRSMI-RLM, Mr. E. A. Verchot
Chief, Document Section
Redstone Arsenal, AL 35809

Commander
US Army Armament Materiel Readiness Command
ATTN: DRSAR-MP-PC
DRSAR-RDP
DRSAR-RDM
DRSAR-RDT, Dr. Daryl Penrod
DRSAR-RDT
DRSAR-ASF, Mr. H. Wohlferth
DRSAR-LEP-L
Rock Island, IL 61299

Commander
US Army Electronics Command
ATTN: DRSEL-TL-ME, Mr. Dan Lichenstein
DRSEL-TL-ME, Mr. A. J. Raffalovich
DRSEL-TL-ME, Mr. G. Platau
DRSEL-PP-EM2, Sarah Rosen
Fort Monmouth, NJ 07703

Director
US Army Tank-Automotive Research
and Development Command
ATTN: DRSTRA-KMD
Warren, MI 48090

Commander
US Army Materials & Mechanics Research Center
ATTN: DRXMR-FR, Dr. G. Thomas
DRXMR-PL
Technical Information Section
Watertown, MA 02172

Director
US Army Production Equipment Agency
Rock Island Arsenal
ATTN: DRXPE-MT, Mr. H. Holmes (2)
Rock Island Arsenal, IL 61299

Commander
USA Troop Support & Aviation Materiel
Readiness Command
ATTN: DRSTS-MEU(2), Mr. E. Dawson
DRSTS-ME(2), Mr. C. Sims
DRSTS-MEN(2), Mr. L. D. Brown
DRSTS-MEL(2), Mr. Bell
DRSTS-MET(2), Mr. Ceasar
P.O. Box 209, Main Office
St. Louis, MO 63166

Commander
Corpus Christi Army Depot
ATTN: DRSTS-MES (STOP 55) (2)
DRSTS-MESA, Mr. T. Tullos (2)
DRSTS-MESP, Mr. Bulloch (1)
Corpus Christi, TX 78419

Commander/Director
Chemical Systems Laboratory
USA ARRADCOM
ATTN: DRDAR-CLB-PM
Bldg E5101
Aberdeen Proving Ground, MD 21010

Chief
Benet Weapons Laboratory
LCWSL, USA ARRADCOM
ATTN: DRDAR-LCB
DRDAR-LCB-TL
Watervliet, NY 12189

Director
US Army Engineer Waterways
Experiment Station, P.O. Box 631
Corps of Engineers
ATTN: Mr. Hugh L. Green, WE SSS1
Vicksburg, MS 39180

Commander
US Army Medical Bio-Engineering Research
and Development Laboratories
Fort Deterick
ATTN: Dr. C. Wade
Frederick, MD 21701

Commander
USA Aviation Research & Development Command
ATTN: DRDAV-EQA, Mr. W. McClane
4300 Goodfellow Blvd
St. Louis, MO 63120

Commander
Harry Diamond Laboratories
ATTN: Mr. N. Kaplan
Mr. J. M. Boyd
Library
Washington, DC 20438

Commander
Tobyhanna Army Depot
ATTN: Mr. A. Alfano
Tobyhanna, PA 18466

Director
US Army Ballistic Research Laboratory
USA ARRADCOM
Bldg 328
Aberdeen Proving Ground, MD 21005

Commander
US Army Materiel Development & Readiness Command
ATTN: DRCPM-UA, Mr. C. Musgrave
DRCPM-LH, Mr. C. Cioffi
DRCPM-HLS-T, Mr. R. E. Hahn
P.O. Box 209
St. Louis, MO 63166

Commander
Natick Research & Development Command
Natick, MA 01760

Commander
US Army Engineer Research & Development Labs
Fort Belvoir, VA 22060

Department of the Navy
Naval Air Systems Command
ATTN: Mr. John J. Gurtowski (AIR 52032C)
Washington, DC 20360

Naval Ordnance Station (NOSL)
ATTN: Mr. W. J. Ryan, Code 5041
Southside Drive
Louisville, KY 40214

Naval Avionics Facility
ATTN: Mr. B. D. Tague, Code D/802
Mr. Paul H. Guhl, D/033.3
21st and Arlington
Indianapolis, IN 46218

Commander
US Naval Weapons Station
ATTN: Research and Development Division
Yorktown, VA 23491

Commander
Aeronautical Systems Division
ATTN: Mr. W. Scardino, AFML/MXE
Mr. T. J. Aponyi
Composite and Fibrous Materials Branch
Nonmetallic Materials Division
Wright-Patterson Air Force Base, OH 45433

Dr. Robert S. Shane, Staff Scientist
National Materials Advisory Board
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, DC 20418

US Army Air Mobility R&D Laboratory, Headquarters
Advanced Systems Research Office
ATTN: Mr. F. Immen, MS 207.5
Ames Research Center
Moffet Field, CA 94035

Naval Ship Engineering Center
ATTN: Mr. W. R. Graner, SEC 6101E
Prince George's Center
Hyattsville, MD 20782

Mare Island Naval Shipyard
Rubber Engineering Section
ATTN: Mr. Ross E. Morris, Code 134.04
Vallejo, CA 94592

Hanscom Air Force Base
ATTN: Mr. R. Karlson, ESD/DE, Stop 7
HQ, ESD
Bedford, MA 01731

Naval Air Development Center
Materials Laboratory
ATTN: Mr. Coleman Nadler, Code 30221,
Div, AVTD
Warminster, PA 18974

Defense Documentation Center (12)
Cameron Station
Alexandria, VA 22314

Commander
US Army Armament Research & Development Command
Plastics Technical Evaluation Center
ATTN: Mr. H. Pebly
Mr. A. Landrock
Dover, NJ 07801

Technical Library
ATTN: DRDAR-CLJ-L
Aberdeen Proving Ground, MD 21010

Technical Library
ATTN: DRDAR-TSB-S
Aberdeen Proving Ground, MD 21005

Director
US Army TRADOC Systems Analysis Activity
ATTN: ATAA-SL (Technical Library)
White Sands Missile Range, NM 88002

Weapon System Concept Team/CSL
ATTN: DRDAR-ACW
Aberdeen Proving Ground, MD 21010